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Front Cover: Giant Sweet Potato *Ipomoea polpha* subsp. *latzii* is a rare plant endemic to central Australia. (Peter Latz)

Back Cover: The Weebill *Smicrornis brevirostris* was one of the most frequently recorded species in a study of birds at Mickett Creek near Darwin. (Con Foley)

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History of the East Point monsoon forest

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Abstract

The 135-hectare East Point Reserve, much of which forms a peninsula projecting into the Beagle Gulf from the city of Darwin, contains a significant remnant of coastal monsoon forest and is abutted in part by mangroves. Historical evidence suggests that monsoon forest once occupied almost all the peninsula, whereas the remnant now occupies 20% of it. Almost half the forest loss occurred prior to 1945 associated with use of the peninsula by the Australian military. The other half was cleared for a golf course and other purposes that we could not identify between 1945 and 1963, mostly between 1955 and 1963. Cyclone Tracy inflicted severe damage to the forest in 1974 but most tree species resprouted. The mangrove stand on the north side of the base of the peninsula has retreated coastward, thickened and extended westward, whilst a smaller stand on the southern side was cleared and has almost disappeared. Since taking over management of the area in 1984, Darwin City Council has revegetated about 20% of the peninsula. Agile Wallabies *Macropus agilis* present in the Reserve proliferated during the 1980s, damaging remnant forest and replantings, but the population returned to much lower densities during the 1990s following closure of most watering points. Significant on-going management issues for the forest include the cost of further revegetation, and weed control. Invasion of remnant forest by Poinciana *Delonix regia*, an attractive non-native tree, may prove to be a controversial management issue in the future.

Introduction

East Point Reserve is an iconic part of the city of Darwin with natural, historical and recreational values. It features prominently in the experience of residents and visitors to Darwin. Much of the reserve's 135 ha is a peninsula, supporting a regionally significant remnant of the coastal monsoon forest which once covered most of the peninsula (Panton 1993). Since 1984, Darwin City Council has undertaken extensive revegetation, the aim being to restore majority coverage of monsoon forest as patches embedded in open areas used for recreation and for grazing by Agile Wallabies *Macropus agilis* (Clouston 2000).

East Point peninsula (12°24'30"S, 130°50'E) (Figure 1) projects *c.* 2.5 km into the Beagle Gulf from a base 6 km north of the Darwin CBD. It comprises a more or less flat, lateritic plateau to a maximum altitude of 11.2 m above sea-level, surrounded for

the most part by low cliffs (Clouston 2000). The isthmus – the current site of Lake Alexander – was a low-lying, swampy flat with coastal sand-dunes on either side while the north side, near the current Spot-On Marine, comprised chenier (coralline sand) (Clouston 2000). The peninsula is well-drained with no natural permanent water. A well dug to 27 m in 1932 contained only salt water (Dermoudy & Cook 1991). The climate is monsoonal tropical as for Darwin, with a mean annual rainfall of approximately 1,700 mm falling predominantly between November and April, and with high temperatures (daily maxima mostly >30°C) throughout the year.

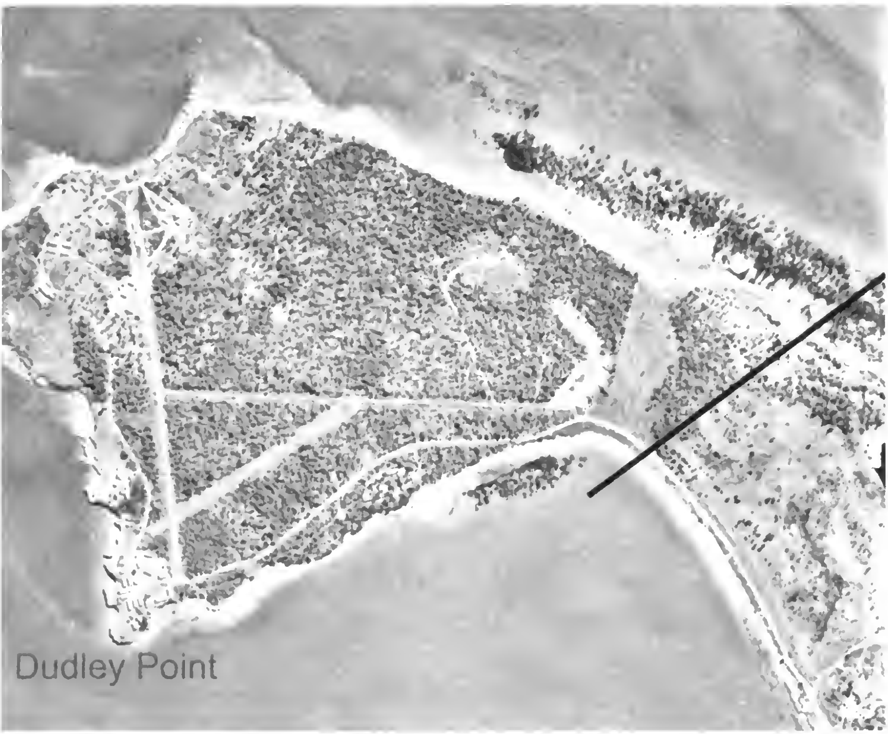

Figure 1. East Point, aerial photograph from 1943, when the military were active on the peninsula; Dudley Point in the south-west is labelled (north is approx. to top of photo). The heavy black line at the base of the peninsula marks the boundary of the area of monsoon forest in 1941 and only areas beyond this line were included in the quantitative analysis of change in forest cover. © Northern Territory of Australia.

East Point peninsula was a military reserve from 1932 to 1963, was managed by the East Point Reserve Trust for recreation from 1964 to 1984, and has been managed by Darwin City Council since then (Griffiths *et al.* 2005).

As background to a field study of the success of regeneration in promoting natural dispersal of monsoon forest plants, we compiled historical information on the vegetation, which is presented here. Our main aim is to document the causes and timing of loss of monsoon forest vegetation and the nature and timing of revegetation.

Methods

We examined aerial photographs of the entire peninsula taken in 1941, 1943, 1945, 1955, 1963, 1974, 1985, 1991, 2002. Three of these (1943, 1974, 2002) are presented here, and a sequence of five (1941, 1974, 1985, 1991, 2002) were reproduced in Griffiths *et al.* (2005). We spoke with parks and gardens staff of Darwin City Council, and to Audrey and Stan Kennon who were members of the Darwin Golf Club from soon after it began operating in the East Point area in 1930 until after it moved elsewhere in 1974 (James 1980a). We also consulted a range of published and archival material and a number of other longer-term residents of Darwin.

For quantitative analysis, we defined East Point as the area west of the line shown in Figure 1, an area of *c.* 105 ha. The boundary line is just beyond where Lake Alexander is now. We chose this line as it was the eastern limit of monsoon forest in the first aerial photograph, taken in 1941. For areas outside this we could only have guessed at the nature of the original vegetation. Aerial photographs were georectified and a grid of points imposed at a field scale of 25 m intervals (1,798 points). For each image, the vegetation at each point was classified as monsoon forest, regeneration, or cleared. Apparent natural infilling or marginal creep of the monsoon forest was included as monsoon forest. Regeneration was only counted if it had a more or less closed canopy, as early-stage regeneration could not be consistently distinguished from grassland. Scattered trees and plantations not associated with revegetation (for example, trees around the military museum and historical relicts) were classified as cleared. The area of vegetation patches was estimated from the number of grid points centred within each.

Original vegetation

There is no detailed record of the nature of the original vegetation, but there is no reason to doubt the interpretation of Panton (1993) that most of the peninsula was originally covered by "monsoon rainforest". Archival images dating back to 1890 show monsoon forest (Figure 2). Aerial photographs taken during World War II when there was much more extensive vegetation cover than at present show no substantial variation in the appearance of the canopy (Figure 1), suggesting that nearly all the original vegetation of the plateau was the same as that of the current remnant monsoon forest. The rather uniform geology, soils and drainage across the plateau also provide a sensible ecological basis for this interpretation.

Figure 2. Archival images of the East Point road, Darwin NT, showing vine-thicket vegetation: A, B. *c.* 1890 (Will Barnes); C. *c.* 1900 (photographer unknown); D. 1934 (photographer unknown). A-C reproduced with permission from the State Library of South Australia (A - catalogue number B 53790; B - B 53812; C - PRG 2801/1/379); D reproduced courtesy of Australian War Memorial.

Based on an extensive floristic survey of the main remnant forest patch (Franklin & Lawes, unpubl. data), the forest belongs to Group 9 of Russell-Smith (1991) – "semi-deciduous rain forests and vine thickets associated with a variety of well to excessively drained coastal and subcoastal landforms" – and more specifically to the sub-coastal sub-group typical of slumping, lateritic coastal cliffs. This vegetation contains a great diversity of tree, shrub and vine-thicket species and cannot be simply characterised by a few of them, though we note a particular prevalence of Grey Boxwood *Drypetes deplanchei*, Tuckeroo *Cupaniopsis anacardioides*, *Miliusa brahei*, Strychnine Tree *Strychnos lucida*, *Tarenna pentamera* and *Antiaris toxicaria*.

A photo taken *c.* 1915 (photographer unknown, http://www.territorystories.nt.gov.au /handle/10070/7451, accessed 2 Sept. 2009) shows *Casuarina* trees growing on top of the coastal cliff. It appears to have been taken from Dudley Point (Figure 1) facing north. The trees are presumably Horsetail Oak *Casuarina equisetifolia*, also known as Coastal She-oak, a common littoral tree around Darwin and present at the site to this day.

Aerial photographs from World War II (e.g. Figure 1) show an extensive band of mangal (mangrove forest or shrubland) along the north shore of the isthmus extending about one-third of the way along the peninsula, and a smaller band on the southern shore near the base of the peninsula.

Clearing the vine-thicket (1932-1963)

The Australian military was evidently the first occupant to substantially modify the vegetation of East Point. Military construction commenced in 1932 and peaked from 1939 to 1943 (Dermoudy & Cook 1991). Forest cover in 1941 (the date of the earliest aerial photograph available to us – it is of poor quality) was 80%, declining to 61% by the end of World War II (Figure 3). In 1941, cleared areas were associated with military buildings and road easements. Buildings were concentrated in three areas: the north-west section near the current military museum and historical relicts; at Dudley Point; and on the south coast near the current site of Peewee's restaurant, as also illustrated in the 1943 photograph (Figure 1). By 1943, a number of areas had been cleared near the base of the peninsula that were associated neither with buildings nor roads. Between 1943 and 1945, clearing was mainly associated with what appears to be a small racecourse.

Stocker (1966) described how monsoon forest disturbed by military activities at East Point was subsequently burnt annually, converting it to a grassy woodland and eliminating all fire-sensitive monsoon forest species. The 1941 aerial photograph shows what appears to be about two hectares of shrubland around the military installations in the north-west of the peninsula – clearly contrasting with the monsoon forest – which in 1943 appears to be grassland; we interpret this as corresponding with Stocker's description.

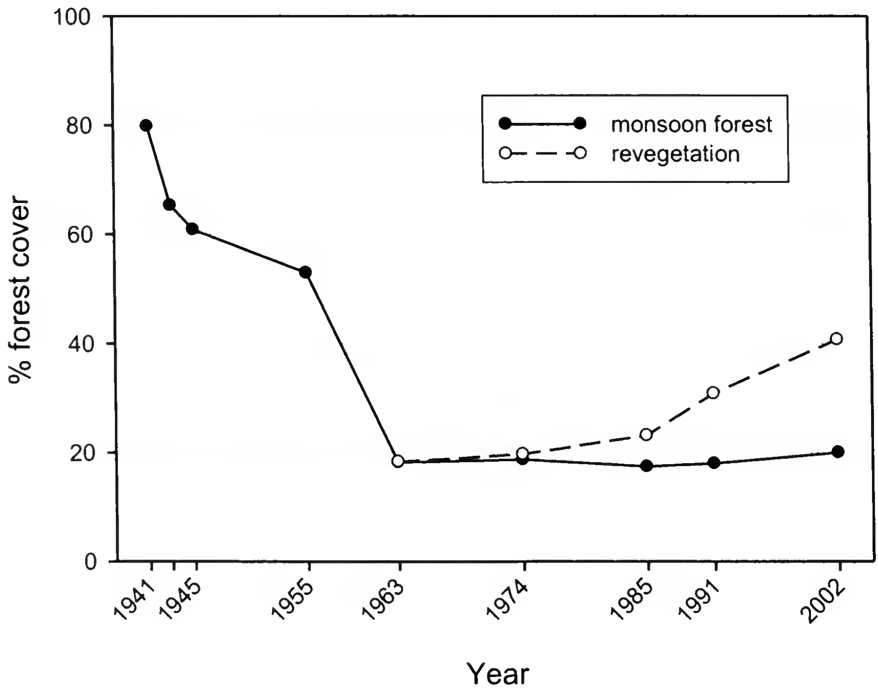

Figure 3. Timeline of forest clearing and revegetation at East Point, Darwin NT, based on eight aerial photographs.

The Darwin Golf Club began operations in 1930 in the vicinity of the Fannie Bay Gaol, being moved to the East Point isthmus near the current Lake Alexander in 1934 to make way for an expansion of the "Ross Smith airstrip ... for the Melbourne air race" (James 1980b). Clearing of the area defined for this study commenced after World War II, the 1955 image showing four holes reaching from the current site of Lake Alexander along the northern side of the Peninsula for about half its length, resulting in the loss of a further 8% of the peninsula forest. Between 1955 and 1963, the course was restructured and nine holes built on the peninsula, reaching from the current site of Lake Alexander to the historical relicts near the current military museum. This involved the clearing of all remaining monsoon forest on the northern third of the peninsula. In 1974 (Figure 4), the golf course was closed and the Club moved to its current site at Marrara.

The central part of the peninsula was also cleared between 1955 and 1963, but we have been unable to ascertain by whom or for what purpose. The combination of this

and clearing for the golf course between 1955 and 1963 resulted in loss of forest cover over 34% of the peninsula.

Figure 4. East Point, Darwin NT, aerial photograph from 1974, with the two remnant patches of monsoon forest numbered. This was the year the golf course closed and a few months before Cyclone Tracy. We interpret the vegetation patch in the centre as long grass prior to or in the very early stages of forest regeneration. © Northern Territory of Australia.

Two remnant patches of monsoon forest remained in 1974 (Figure 4). The main patch, extending along almost the entire southern margin of the peninsula and on either side of the main access road, had an area of *c.* 19.7 ha, whilst patch 2 covered *c.* 1.1 ha. These patches remain (2009) and indeed have expanded in places around the margins (Figures 3, 5), though patch 1 has been subject to minor further disturbance along the south coast and patch 2 is heavily disturbed by grazing horses (DCF pers. obs. 25 August 2009).

Revegetation

The four major areas of revegetation present in 2002 (numbered in Figure 5) have individual histories.

Figure 5. East Point, Darwin NT, aerial photograph from 2002. Patches of revegetated forest in the centre of the peninsula are scarcely distinguishable from the original monsoon forest. Note that Lake Alexander has been built. The canopy along the road through the main original patch monsoon forest is smooth; we believe this to be Poinciana *Delonix regia*. © Northern Territory of Australia.

Patch 1 (3.3 ha) was revegetated by the Northern Territory Government (Stan Kennon pers. comm.). In 1974 (Figure 4) it was already evident though lacking a canopy and with no more than several remnant trees; we interpret this as unmown grass prior to or soon after planting. This interpretation matches well with statements by Darwin City Council staff that planting took place about ten years prior to 1984. They also stated that the plantings were not watered. The patch had a reasonably well-formed canopy in 1985 and a well-formed canopy by 1991.

Patch 2 (0.5 ha; Figure 5) had its nucleus around original trees, which examination on 25 August 2009 suggests may have been *Acacia auriculiformis*. Darwin City Council staff report that it was replanted by (the then) Northern Territory University before

Darwin City Council took over management of the Reserve in 1984. It had a well-formed canopy in 1985.

Darwin City Council took over management of East Point Reserve in 1984 and commenced an ambitious revegetation program in 1985 – patches 3a, b & c (16.6 ha; Figure 5). Scattered trees are evident in the area prior to planting, though many fewer in 1985 than in 1974. Darwin City Council staff advised that many of the remnant trees were *Maranthes corymbosa*, several of which remained until at least 2008 and have been placed on the register of significant trees. Several planted African Mahoganies *Khaya senegalensis* were still there in 2008. *Dodonaea platyptera* (a shrub) and *Cupaniopsis anarcardioides* (a small tree) also persisted at the site.

Revegetation of patch 3 commenced with the area being ripped in a spiral line with 5 m increments using a large bulldozer. A water main was installed, seven irrigation points established, and seedlings planted at 5 m intervals along the spirals. Species planted in 1985 were: *Maranthes corymbosa*, Yellow Flame Tree *Peltophorum pterocarpum*, Banyan *Ficus virens*, Milkwood *Alstonia actinophylla*, Indian Siris *Albizia lebbeck* and Darwin Black Wattle *Acacia auriculiformis*, and possibly also Damson *Terminalia microcarpa* and Red Condoo *Mimusops elengi*. This selection was based on a combination of local occurrence and availability in a local nursery (Darwin Plant Wholesalers at Lambells Lagoon). Many of these plantings were fenced with individual tree guards for protection against browsing Agile Wallabies *Macropus agilis*.

In 1990, a fire burnt most of patch 3c and part of 3b. Its effect in thinning the incipient canopy is clearly evident in the 1991 aerial photograph, but has disappeared by 2002 (Figure 5). It was reported to us as burning 13 ha (this figure presumably includes grassland); our estimate from the 1991 photo is that 6.8 ha of revegetation patch 3 was burnt.

Replacement plantings took place in the early 1990s in collaboration with Greening Australia. These were of the same species and within tree guards, though Agile Wallabies were often able to reach through these. At this stage, the area between the guards was slashed each year, and it was not until soon after 1994 that slashing ceased so that natural regeneration could occur (Simon Stirrat pers. comm.).

Three major weeds proliferated with the regeneration and were subject to control measures: Perennial Mission Grass *Pennisetum polystachion*, Gamba Grass *Andropogon gayanus* and the scrambling shrub Lantana *Lantana camara*. Following an intense campaign to control Lantana patches in forest gaps (*c.* 2003-05; Jamie Lewis pers. comm.), infill planting of these gaps commenced in about 2005. Plantings were from seed and cuttings collected at East Point and grown in the Council nursery, and also of East Point species provided by Greening Australia but potentially sourced elsewhere in the Top End. All these plantings remain staked as at 2008. Use of herbicides and machinery during the Lantana campaign (and during other weed control) impacted severely on the seedling bank in affected areas. Canopy closure has

now largely excluded the three weed species, except around the margins where control is on-going.

The narrow band of vine-thicket along the north coast of the peninsula (patch 4, 4.1 ha; Figure 5), much of which is growing on coralline sand, was virtually absent in 1974 but for some trees or shrubs at the eastern end – in the vicinity of the present mangrove board walk. The eastern end shows substantial thickening in the 1985 aerial photograph, whereas the western end began to develop substantially only later, and notably between 1991 and 2002. It has, for the most part, been self-sown, but with supplementary plantings by Darwin City Council at the eastern end.

The tiny (*c.* 0.1 ha) patch 5 was present and apparently well-developed in 1974 but absent in 1963. In March 2008, a planting of 1,400 trees formed another patch. This comprises *c.* 1 ha and lies to the immediate west of patch 3a (Figure 5), between it and the road near the military museum.

Mangroves

The small mangrove patch on the southern side of the base of the peninsula was completely cleared by Water Resources in *c.* 1964-65, the few remaining trees being regrowth (Helen Haritos pers. comm.). This report is consistent with the aerial photograph record (e.g. Figures 1, 4 and 5) which shows the patch intact up until 1963 but virtually absent in 1974, with growth of a few trees since then. The aerial photograph sequence also suggests substantial change to the more extensive mangrove communities on the northern side, with shoreward retreat, considerable thickening, and extension westwards. Major changes took place between 1974 and 1985.

Cyclone Tracy

Tropical Cyclone Tracy struck Darwin on Christmas Day in 1974 – the year the Darwin Golf Club moved from East Point to Marrara. Stocker (1976) provided photographs and some description of damage to native vegetation around Darwin based on an inspection seven weeks later. Two photos of the East Point monsoon forest (Stocker 1976; page 28) show extensive loss of crowns and considerable damage to branches but also vigorous regeneration of most crowns. Stocker noted that the monsoon forest at East Point was damaged less than other monsoon forests notwithstanding its exposed position.

Fox (1980) evaluated the severity of damage and regeneration modes of monsoon forest species at East Point in ten 20 x 20 m plots within a few years after the cyclone, though no survey date is given. Most species resprouted, but a few (particularly *Alstonia actinophylla*) did not. The notably very few seedlings were mainly of *Acacia auriculiformis,* and Fox argued that emergent seedlings may have been suppressed by prolific growth of vines.

Agile Wallabies

As documented in detail by Griffiths *et al.* (2005), the population of Agile Wallabies at East Point exploded to a peak of *c.* 2,000 in the late 1980s from historical levels of *c.* 150 to 400. The increase is believed to be the product of provision of watering troughs in the period 1980 to 1984, and of watering points by Darwin City Council in the mid 1980s for their revegetation program. The mechanism for demographic adjustment is likely to have been improved juvenile survival during the nutritionally-harsh dry season (Stirrat 2003, 2008). As well as generating a problem with collisions on the road through East Point, high densities of Agile Wallabies destroyed many plantings and were perceived to be a threat to natural regeneration of the remnant monsoon forest. Stirrat (2002) found that Agile Wallabies at East Point consumed mainly grasses and other herbs during the wet season, but consumed a much wider range of foods including browse, leaf litter and roots during the dry season. Using exclosure experiments, Stirrat (2000) found that Agile Wallabies suppressed survival of monsoon forest seedlings, severely depleted the leaf litter layer and disturbed the soil. However, the wallabies browsed only a few monsoon forest species "notably the vines *Capparis sepiaria* and *Flagellaria indica*" and the depressed survival of seedlings may have been due to indirect effects such as dehydration following the loss of leaf litter.

The supply of water available to Agile Wallabies was progressively reduced to just a few troughs by 1995 (Griffiths *et al.* 2005). The population declined progressively through the 1990s and by 2000 had returned to what are believed to be historical levels of several hundred.

Discussion

Reduction of the East Point monsoon forest to *c.* 20% of its original area is attributable to the military and to the Darwin Golf Club, though we have been unable to identify the agent responsible for *c.* 22% of the clearing. Both activities occurred in an era when little value was placed on native vegetation in general and monsoon forest in particular, despite the latter having only scattered occurrence in the Darwin region (Panton 1993) and elsewhere in the Top End (Russell-Smith & Dunlop 1987).

The loss of monsoon forest for expansion of the golf course after 1955 is particularly tragic and a testament to a lack of forward planning, given that the golf course was closed less than 20 years later in 1974. It was reported (unpublished documents and several personal communications) that the golf course was moved to Marrara because of a government plan to build a road (the "Palmerston Freeway") connecting Fannie Bay to Nightcliff through the golf course at the base of the peninsula, presumably across the mouth of Ludmilla Creek. The plan was subsequently shelved, perhaps because Cyclone Tracy demonstrated the vulnerability of mangrove areas, and Dick Ward Drive appears to have been developed as an alternative route. Another

suggestion put to us was that the decision was a political move to encourage the development of Marrara as a suburb. The two explanations are potentially compatible.

Overt human interference was responsible for the near-complete loss of the mangrove patch on the southern side of the peninsula. We have been unable to determine why the patch was cleared by Water Resources, but it was directly adjacent to a water testing laboratory established and run by that organisation for at least the period 1966 to 1974 (H. Haritos, pers. comm.). We can only speculate as to the causes of the increase and movement of the mangroves on the northern side. This patch is close to the mouth of Ludmilla Creek and may be subject to substrate instability associated with freshwater outflows. Urbanisation of the creek's catchment could have increased storm-water and nutrient run-off. Freshwater flows are known to improve mangrove growth (Semeniuk 1983). A fertiliser effect from the Ludmilla Wastewater Treatment Plant which discharges off the north coast of East Point, is also possible. Parallel increase and shoreward movement of mangroves occurred around and to the east of Buffalo Creek (12 km north-east of East Point) between 1974 and 2004; the rate of change was doubled in a mangrove swamp impacted by changes to run-off and construction of a sewage treatment plant, compared to a nearby unaffected swamp (Williamson *et al.* in press).

Revegetation work, undertaken mainly by Darwin City Council, demonstrates long-term commitment to the future of the Reserve as a historic, conservation, recreation and tourist resource, backed by a plan of management (Clouston 2000). This work has not been without problems and challenges; fire, weeds and proliferation of Agile Wallabies have all proven to be substantial management issues. Weed management and further revegetation will require substantial resources in the future. Notwithstanding, Darwin City Council (mainly) and other agents have succeeded in doubling the area of monsoon forest on the peninsula from its low point in 1974. We are currently undertaking an assessment of the extent to which this revegetation has rejuvenated forest ecosystem structure and processes. However, even a rather cursory examination confirms success in creating a closed canopy (Figure 6), encouraging natural regeneration, and creating habitat for monsoon forest specialists such as the Rainbow Pitta *Pitta iris*, a litter-foraging bird.

The great importance of peri-urban habitat patches such as these as refuges for fauna that cannot persist in the greater landscape matrix, perhaps due to prevailing fire regimes, was demonstrated by Price *et al.* (2005). Despite the strong argument that all patches of monsoon forest in the Northern Territory should be maintained because they are inter-dependent, such that the loss of patches may reverberate more widely through the system (Price *et al.* 1995; Bach & Price 2005), a number of monsoon forest patches remain under significant pressure due to development, weeds and fire regimes in particular (Russell-Smith & Bowman 1992; Panton 1993).

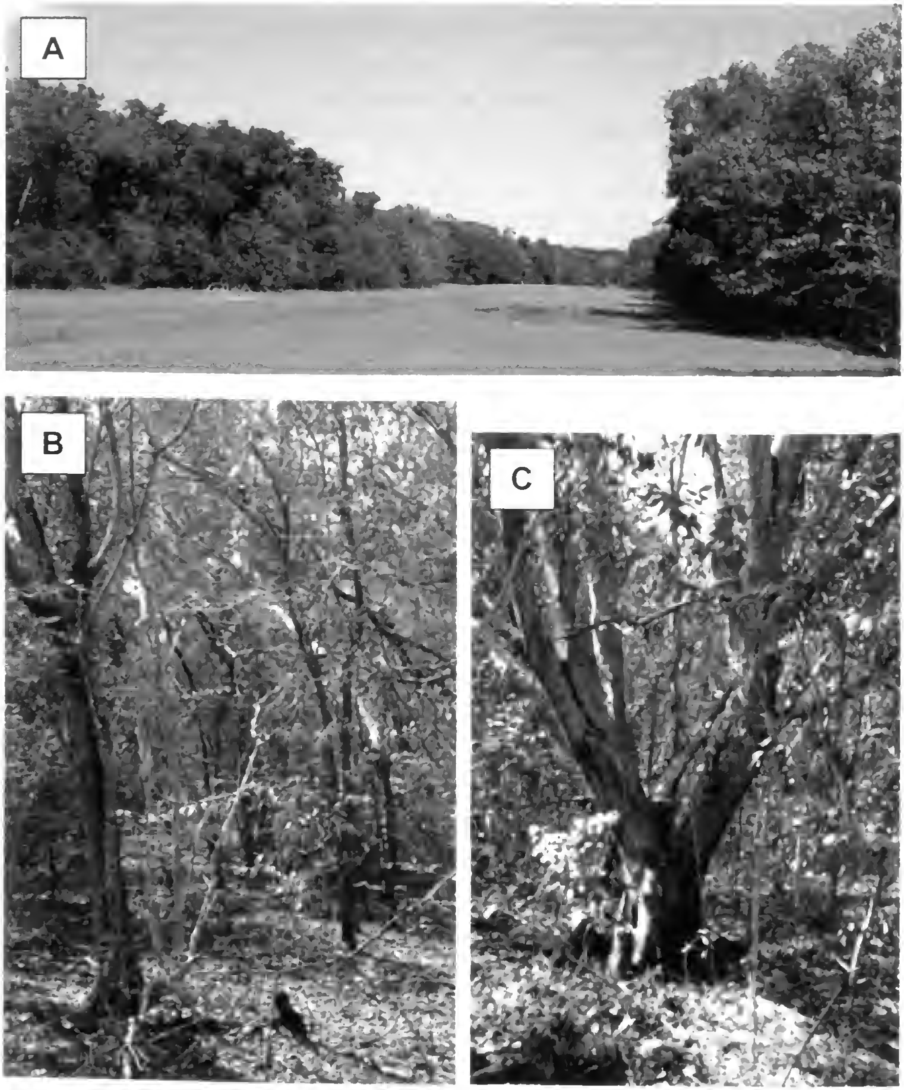

Figure 6. The largest patch of revegetated monsoon forest (patch 3a in Figure 5) now has a closed canopy and much natural regeneration, and in places resembles an undisturbed monsoon forest. A. original monsoon forest remnant on left, revegetation patch 3a on right, looking westward; B., C. interior of patch 3a. Photographs taken 13 September 2009. (D. Franklin)

As resources become available, Darwin City Council intends extending the landscape design already in place, in which patches of monsoon forest are embedded in a grassland matrix, by creating further patches.

A significant and potentially politically-fraught management issue for the future is the invasion of otherwise intact monsoon forest by the non-native Poinciana *Delonix regia* (Toohey 2001). This attractive tree provides mass displays of red flowers during October and November. It is abundant along the southern margin of the main patch of remnant monsoon forest and our observations suggest that is expanding into the forest.

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The woody vine Opilia *Opilia amentacea* is common in the East Point monsoon forest. (Don Franklin)

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Distribution and conservation status of the Giant Sweet Potato, a rare Aboriginal food plant from Central Australia

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Abstract

The Giant Sweet Potato, *Ipomoea polpha* subsp. *latzii* R.W.Johnson (Convolvulaceae), or "Antjulkinah", is a rare plant endemic to central Australia, and features prominently in the mythology of the Traditional Owners of the area, the Anmatjerre people. The taxon is known from three sub-populations and has a highly restricted geographic distribution. Our study of the distribution, density and population size of *Ipomoea polpha* subsp. *latzii* incorporated traditional ecological knowledge, and led to the identification of an additional extensive sub-population. The distance-transect method was used to calculate estimates of population size and density for the Giant Sweet Potato, and is one of the only published examples of the application of this method to a plant species. We estimate the area of occupancy of the taxon to be at least 26.7 km^2, significantly greater than the population estimate reported by a survey in 1987. Our data support listing the species as Vulnerable under IUCN (2008) criterion D2.

Introduction

Limited resources are available for the management of threatened plant species. Prioritization of these resources may be achieved by ranking species according to their perceived threat of extinction. The IUCN criteria (IUCN 2008) are widely used in Australia, by state, territory and federal governments, to assess the conservation status of species and to assign a ranked category of extinction risk. Distribution and abundance data for taxa are required to make an assessment, and these data are frequently costly and time-intensive to collect. The conservation status of many plant

species in Australia has yet to be determined. For example, in the Northern Territory, of the 4,502 recognised taxa, 707 taxa (15.7%) are so poorly known they have been assigned to the category of "data deficient" (NRETAS 2009). New or alternative methods to collect information on density, distribution and population size of species in an accurate and cost effective way would be of value and could be used to augment more commonly used survey techniques. One such method is the incorporation of traditional ecological knowledge (TEK) into projects assessing the conservation status of species.

Traditional ecological knowledge is defined as the knowledge base acquired by indigenous people over long time periods through direct contact with the environment and includes detailed knowledge of plants, animals and natural phenomena (Bourque *et al.* 1993). Indigenous knowledge can be used to assist in the assessment of the conservation status of rare species by providing information on distribution, density and population size. For example, TEK has been used to delineate the distribution of several rare Australian mammals (see for example Burbidge *et al.* 1988; Baker *et al.* 1993; Pearson & the Ngaanyatjarra Council 1997; Telfer & Garde 2006). Some rare plant and animal species may be of cultural importance to Aboriginal people and should be prioritized for the collection of TEK and for assessment of conservation status.

Ipomoea polpha subsp. *latzii* (Convolvulaceae), the "Giant Sweet Potato", is a rare plant endemic to Central Australia. The two other disjunct, but more widespread, sub-species of *I. polpha* occur in Queensland (Johnson 2006). Plants develop multiple edible tubers (Figure 1), most of which are of similar size to or smaller than the commercial sweet potato (*Ipomoea batatas*). However, some tubers can be enormous. The largest tuber weighed by Soos and Latz (1987) was 2.6 kg. The Giant Sweet Potato is called "Antjulkinah" by the Anmatjerre, the local indigenous people, and features strongly in their mythology. The Anmatjerre people have songs for locating the plants and for "singing him up" (Soos & Latz 1987). The tubers are easily excavated from the sandy soil and roasted on coals or eaten raw, tasting similar to a water chestnut. The Giant Sweet Potato is known to several other groups in the surrounding area (for example Kaytej, Warlpiri and western Alyawarra), although the taxon is not known to occur in these areas (Soos & Latz 1987). *Ipomoea polpha* subsp. *latzii* is thought to have been traded with these and other groups, and to have been eaten during gatherings for ceremonies (Soos & Latz 1987).

A survey in 1987 (Soos & Latz 1987) indicated that the taxon was restricted to an area of approximately 9 by 13 km with an estimated population of 11,000 individuals. The then undescribed taxon (*Ipomoea* A83192 Stirling) was coded as Vulnerable at a national level under the *Environment Protection and Biodiversity Conservation Act* (1999). Potential threats proposed by Soos and Latz (1987) included fires, drought and changes to hydrology. Since 1987 no scientific monitoring of the species had been conducted and extensive bushfires burnt sections of the known distribution of the

species in the winter of 2001. Field work for the present study was conducted in 2005 following 18 months of drought in Central Australia (Australian Bureau of Meteorology 2010).

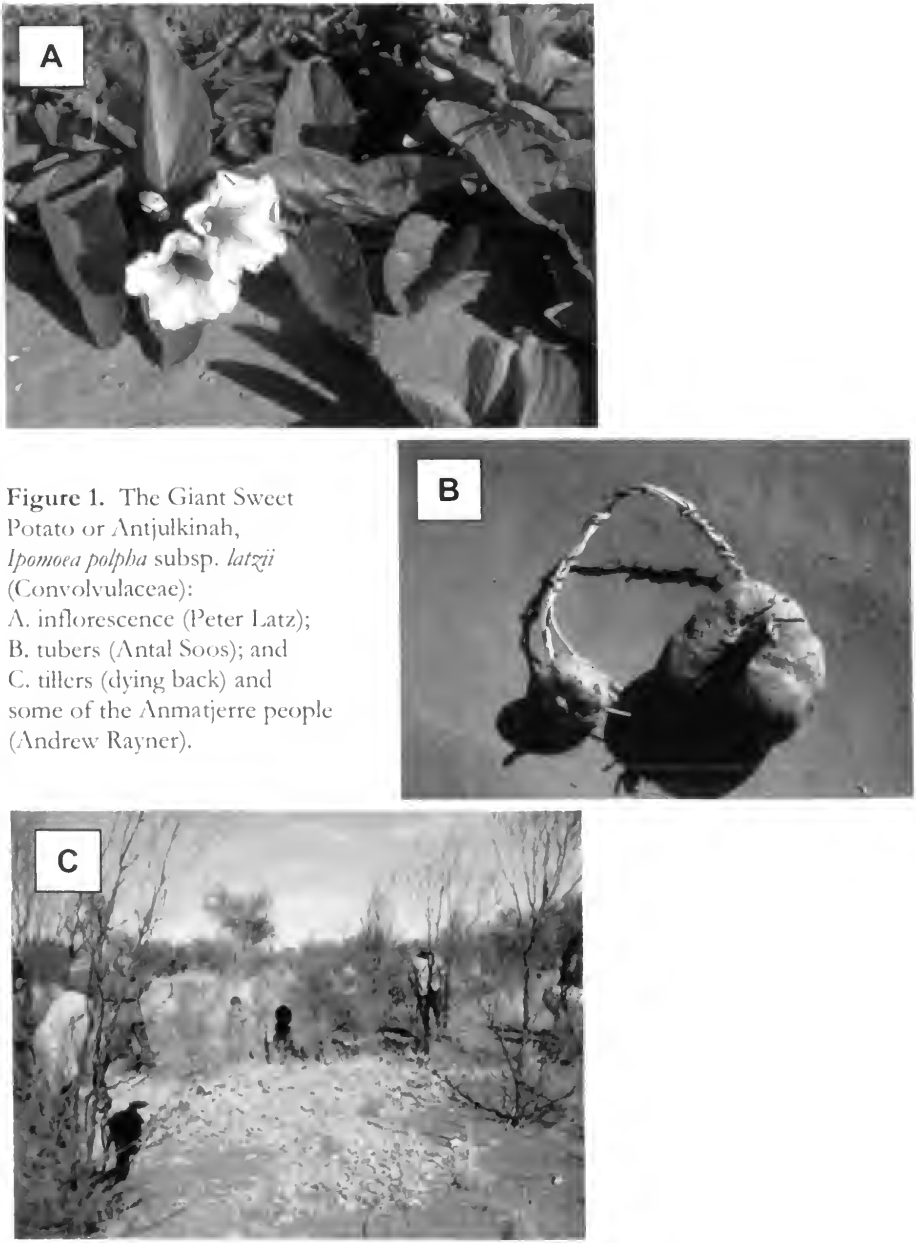

Figure 1. The Giant Sweet Potato or Antjulkinah, *Ipomoea polpha* subsp. *latzii* (Convolvulaceae): A. inflorescence (Peter Latz); B. tubers (Antal Soos); and C. tillers (dying back) and some of the Anmatjerre people (Andrew Rayner).

Importance to the local indigenous community, narrow geographic range of the taxon and few recorded localities prompted the selection of *Ipomoea polpha* subsp. *latzii* R.W.Johnson (Convolvulaceae) for this study. Here we incorporate TEK into the study of the Giant Sweet Potato as it is a plant of utilitarian and cultural significance to the Anmatjerre people. We re-map the extent of *Ipomoea polpha* subsp. *latzii*, calculate population density and size, and compare these to values recorded 18 years prior. We use the data collected to review the conservation status of the taxon under the IUCN guidelines (2008).

Methods

Study species

Ipomoea (Convolvulaceae) is a genus of approximately 500 species globally (Harden 1992). Thirty-three *Ipomoea* species are endemic to Australia and another 17 are naturalised (ANBG 2010). *Ipomoea* species produce large colourful blooms, two of which were illustrated during the voyage of Captain James Cook on the Endeavour (Ebes 1988). *Ipomoea* species are a major carbohydrate source across the Pacific region and throughout the tropical world (Woolfe 1992). A single species, *I. batatas*, is cultivated in more than 100 countries and is the seventh most common food crop in the world, by weight of annual global production (Woolfe 1992). Several species are of commercial value in Australia and are grown as both ornamentals and food crops (Harden 1992). For thousands of years the tubers of *Ipomoea* plants have been harvested for food by Aboriginal people in Australia, including in arid areas (Isaacs 1987; Wightman *et al.* 1992; Latz 1995; Nambatu *et al.* 2009).

Ipomoea polpha subsp. *latzii* was recently described by Johnson (2006). The inflorescence is deep pink with a darker, maroon throat (Figure 1A), although occasionally the species is seen with a white corolla. The plant is perennial, although prostrate runners to 4 m long die back annually (Figure 1C). Tubers enable plants to survive unfavourable conditions, re-sprouting with rain, which falls mostly during summer. The Giant Sweet Potato has been grown at the Alice Springs Desert Park, and seems to be reasonably easy to propagate.

Study site

Ipomoea polpha subsp. *latzii* occurs in an area approximately 200 km north of Alice Springs in central Australia. The area is dominated by Mulga (*Acacia aneura*) and Witchetty (*A. kempeana*) open woodland/shrublands. Mean annual rainfall for the area is 324 mm, falling mostly between November and February (Australian Bureau of Meteorology 2010). From October to March, maximum daily temperatures can be above 40°C, and from June to August minimum daily temperatures can be below 0°C with occasional frosts (Australian Bureau of Meteorology 2010). The soil is a red sandy clay loam with occasional clay pans in low lying areas (Soos & Latz 1987). Soil samples from areas supporting *Ipomoea polpha* subsp. *latzii* and from other localities in

the region did not differ appreciably in pH, electrical conductivity or nutrient content (Soos & Latz 1987).

Mapping distribution

Areas where the Giant Sweet Potato occurs differ only subtly in topography, vegetation type and soil physicochemical properties (Soos & Latz 1987). The open woodland habitat extends for hundreds of kilometres through Central Australia and there is no clear difference between areas where the *Ipomoea* is present or absent. Due to subtle differences in physical and environmental conditions, construction of a distributional model is problematic. To overcome this limitation, TEK of the local Anmatjerre people was used in the search for the rare plant.

Senior Anmatjerre Traditional Owners participated in three field excursions between April and July, 2005, of between one and three days each, to Ahakeye Aboriginal Land Trust, Stirling and Anningie stations. Between three and 17 informants participated in each trip. Informal group discussions were initiated using a large format book summarizing research previously conducted and Traditional Owners took the group to locations where they knew the Giant Sweet Potato to occur (including one previously unrecorded sub-population). A representative from the Central Land Council (CLC) accompanied the group during all three consultations, and protocols for collecting Aboriginal knowledge were guided by CLC staff. Information of religious or cultural significance was recorded by the CLC representative, under the direction of the Traditional Owners, and is retained by the CLC on behalf of the Anmatjerre people. The aim of the consultations was initially to explain the proposed survey and to seek permission for access from Traditional Owners, and subsequently to circumscribe the distribution of the *Ipomoea polpha* subsp. *latzii* sub-populations.

Estimating density and abundance

The distance-sampling method (see Buckland *et al.* 1993; Burnham & Anderson 1998; Thomas *et al.* 2010) was used to estimate the density and abundance of Giant Sweet Potato plants. Observations were made by following a transect and recording the distance from the transect to each *Ipomoea* plant observed. These measurements were used to derive a probability of detection, that is, a model of the distribution of observations as distance from the transect increases. Eleven transects in total were established. The three sub-populations of the Giant Sweet Potato are referred to here as Tinfish-Low Level, Atatirk and Long Range (Figure 2). Transects for the Tinfish-Low Level and Atatirk sub-populations were east-west oriented. For the Tinfish-Low Level sub-population, surveys were conducted along four parallel transects 500 m apart in the northern section, and four at 1,000 m spacing in the southern section. Two transects 1,200 m apart were surveyed in the Atatirk sub-population. One north-south oriented transect was surveyed in the Long Range sub-population. Transects began and ended at least 300 m outside the mapped sub-populations in order to accurately detect and map the edge of the distribution.

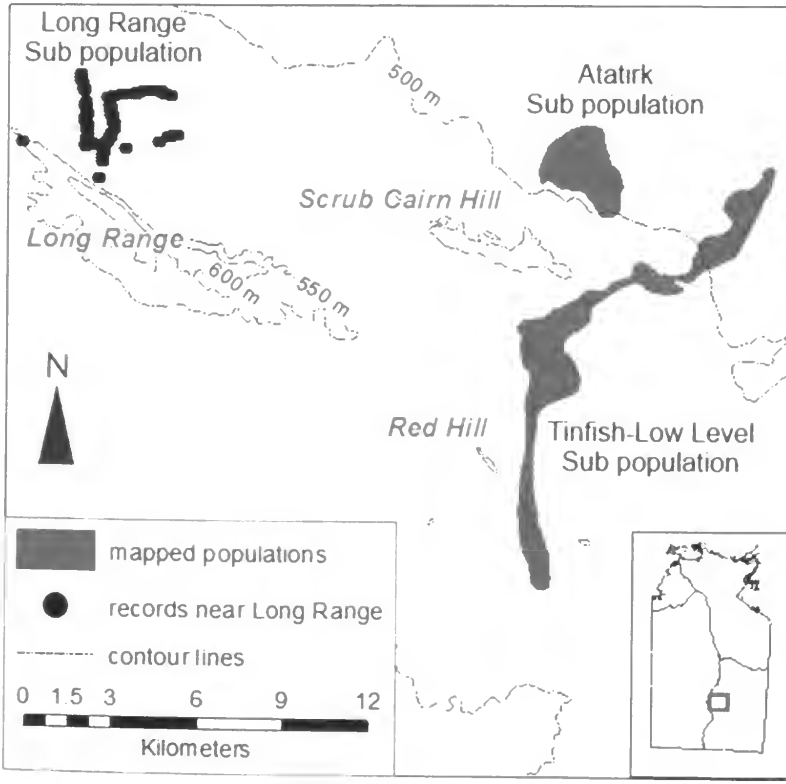

Figure 2. Known locations of *Ipomoea polpha* subsp. *latzii*. Black dots indicate records within the previously unrecorded Long Range sub-population. Inset shows the Northern Territory, Australia with study site indicated by box.

The perpendicular distance from the transect to the centre of each *Ipomoea* plant visible from the transect was recorded to the nearest 10 cm with a tape measure. Although almost all above ground material was dead, the plants were clearly visible from up to 40 m away, as plant crowns were frequently more than one metre in diameter with runners originating from the central part of the plant and scrambling over fallen branches and debris for several metres (Figure 1C). A GPS and compass were used to maintain transects on an accurate bearing and to delineate sub-population boundaries.

The density and abundance of plants were calculated for the three sub-populations with DISTANCE v5 software (Thomas *et al.* 2010). The data were truncated by removing the most distant 5% from each sub-population dataset as recommended by

Buckland *et al.* (1993). Models of the detection function were ranked based on the Akaike's Information Criterion (AICc), chi-square scores and the coefficient of variance (Buckland *et al.* 1993, Burnham & Anderson 1998). A relative difference of two or greater in AICc scores between models demonstrates a clear difference between models, and the model with the lowest AICc was selected. AICc rather than AIC scores were used to rank models, as is recommended by Burnham and Anderson (1998) when sample sizes are small.

Results

Aboriginal Traditional Owners guided the group to a previously unrecorded sub-population of *Ipomoea polpha* subsp. *latzii* (Figure 2). This sub-population, referred to here as "Long Range", is approximately 14 km to the west and slightly north of the Atatirk and Tinfish-Low Level sub-populations. The extent of the Long Range sub-population has yet to be mapped, but adds significantly to the documented distribution of the plant. This sub-population is at least as large as the Atatirk sub-population. The Tinfish-Low Level sub-population boundary was extended by almost 4 km to the south (Figure 3), and covers 1,462.2 hectares (Table 1). The extent of the Atatirk sub-population was extended to the south, east and west (Figure 3), and was 605.9 hectares (Table 1). The area of the Atatirk sub-population was extended by 35%, and that of the Tinfish-Low Level sub-population by 48%, when compared to the 1987 survey of Soos and Latz (1987).

A total of 14.2 kilometres of transect were surveyed within the *Ipomoea* sub-populations, and 1,524 individuals recorded (Table 1). Three detection functions were developed for each sub-population, all with similar AICc, chi-square scores and coefficients of variance (Table 2). High chi-square values indicate a good fit between the statistical distribution predicted by the model and the actual distribution of plants. The coefficient of variance indicates the variance recorded between transects within each sub-population and differed little between models.

Within each sub-population, density estimates of each model were similar, and the density of plants in the Tinfish-Low Level and Atatirk sub-populations did not differ significantly (Table 3). Density estimates ranged from 19.3 to 65.4 individuals per hectare for the Tinfish-Low Level sub-population, and from 18.7 to 48.4 for Atatirk. The Long Range density estimates are based on a single transect and cannot be assumed to represent the sub-population as a whole. Density was higher than for the other sub-populations, and ranged from 43.5 to 72.2 plants per hectare.

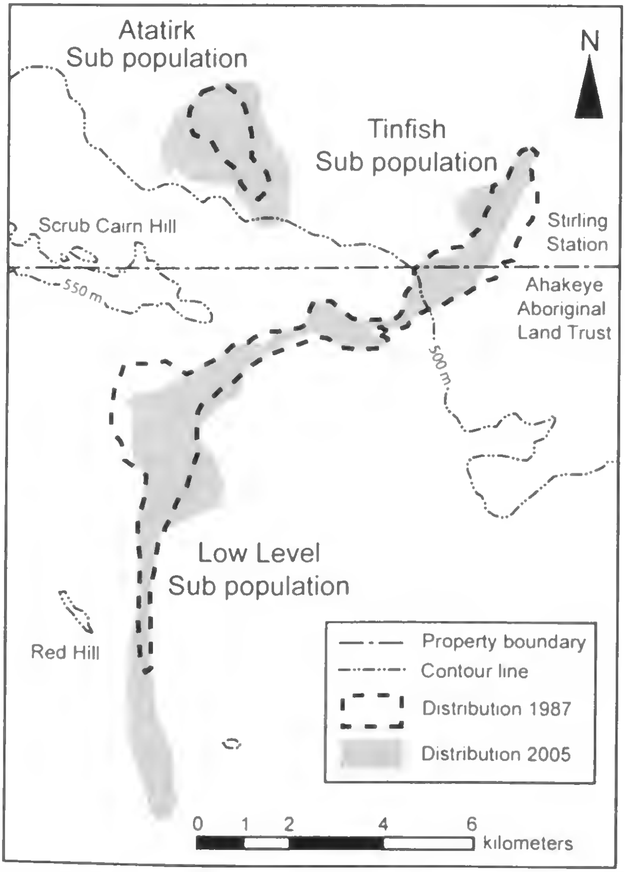

Figure 3. Distribution of *Ipomoea polpha* subsp. *latzii* mapped by Soos & Latz (1987) and during the present study in 2005.

Table 1. Area of *Ipomoea polpha* subsp. *latzii* sub-populations, with numbers and lengths of transects, and numbers of plants counted.

Sub-population name	Area (ha)	No. of transects	Total transect distance (m)	No. of plants recorded
Tinfish-Low Level	1,462.2	8	9,997	1,208
Atatirk	605.9	2	3,153	208
Long Range	>605.9	1	1,091	108
Total	**>2,674.0**	**11**	**14,241**	**1,524**

Table 2. Models selected for the Tinfish-Low Level, Atatirk and Long Range sub-populations of *Ipomoea polpha* subsp. *latzii*. Models are ranked by AICc.

Sub-population / Model	No. of parameters	AICc	ΔAICc	Goodness of fit (*P* for chi-square)	Δ coefficient of variance
Tinfish-Low Level					
Hazard rate, cosine	3	7,084.78	0	0.09	0.264
Half normal, cosine	2	7,085.02	0.24	0.07	0.267
Uniform, hermite polynomial	2	7,086.03	1.25	0.06	0.263
Atatirk					
Half normal	1	914.11	0	0.70	0.21
Uniform, cosine	1	914.63	0.52	0.68	0.21
Hazard rate	2	916.62	2.51	0.60	0.21
Long Range					
Uniform, hermite polynomial	2	492.02	0	0.149	0.111
Half normal, hermite polynomial	1	492.35	0.33	0.274	0.104
Hazard rate	2	493.72	1.37	0.112	0.154

Table 3. Density and abundance estimated for *Ipomoea polpha* subsp. *latzii* in the Tinfish-Low Level, Atatirk and Long Range sub-populations. Population size not calculated (n.a.) for the Long Range sub-population as it is yet to be mapped accurately. CI: confidence interval.

	Density (per ha)		Population	
Sub-population	Mean	95% CI	Estimate	95% CI
Tinfish-Low Level	35.5	19.3–65.4	51,972	28,250–95,615
Atatirk	30.1	18.7–48.4	18,230	11,329–29,335
Long Range	56.1	43.5–72.2	n.a.	n.a.

The total population size of Tinfish-Low Level was estimated to be between 28,250 and 95,615 individuals, and the Atatirk sub-population between 11,329 and 29,335 plants. The population size has not been quantified for Long Range as the distribution of the sub-population has yet to be delineated. We estimate it to exceed the Atatirk sub-population.

Discussion

A new sub-population of the rare *Ipomoea polpha* subsp. *latzii* was identified with the assistance of the Anmatjerre Traditional Owners, thus improving the knowledge base used for assessing the conservation status of the taxon under the IUCN guidelines. Estimates of population size and density of the Giant Sweet Potato were made by applying the distance sampling technique (see Buckland *et al.* 1993; Thomas *et al.* 2010). This study is an uncommon example of application of this method to a plant, rather than an animal, taxon. The total number of individuals, the density and the area of occupancy of the Giant Sweet Potato were greater in 2005 than in 1987, indicating that the population has not declined in the intervening 18 years, despite fires and a recent 18 month drought.

The total number of Giant Sweet Potato plants in the two comprehensively mapped sub-populations ranged from 39,579 to 124,950 individuals, substantially greater than the previous estimate of 11,000 (Soos & Latz 1987). This greatly increased estimate of population size can be attributed to delineation of a larger extent of occupancy and to increased density of plants. The estimated density of *Ipomoea polpha* subsp. *latzii* individuals was higher in 2005 than in 1987. The estimated average density of the Atatirk sub-population was 1 mature plant per hectare in 1987 (Soos & Latz 1987), and between 18.7 to 48.4 plants per hectare in the present study. Soos and Latz (1987) did not describe their methods for calculating density, nor provide confidence intervals for their estimates. However, as the densities calculated in the present study are many times higher, it is likely that at least some of this increase is due to recruitment and not to differences in methodology. The mapped areas of occupancy of the previously mapped sub-populations of the Giant Sweet Potato (Tinfish-Low Level and Atatirk) were also substantially greater in 2005. A large range extension was recorded in the present study in the area south of the Tinfish-Low Level sub-population, and the distribution of the Atatirk sub-population was greater in most directions.

Although an 18 month drought preceded the present study, actively growing Giant Sweet Potato plants were observed during a preliminary trip in March of 2005 which followed substantial rainfall on 3-4 January 2005 (82 mm at Tinfish Well; Bill Sage, pers. comm.). Several episodes of recruitment are likely to have occurred during the 18 years between the surveys and are likely to be associated with periods of high rainfall. Continued monitoring of *Ipomoea polpha* subsp. *latzii* could provide evidence of the role of precipitation in recruitment and range expansion of this taxon. Understanding the drivers of local recruitment dynamics would enable an assessment to be made of population stability and could lead to identification of factors (or combinations of factors) limiting recruitment.

Conservation status

Based on new information from this study, the conservation status of *Ipomoea polpha* subsp. *latzii* was assessed against the IUCN Guidelines (2008), and the taxon qualifies for the category of Vulnerable. The IUCN (2008) criteria for "Vulnerable" section D has three elements which relate to (i) the number of mature individuals (D1), (ii) area of occupancy (D2) and (iii) number of known localities of the taxon (also D2). Under section D1 a population with fewer than 1,000 reproductively mature individuals is classified as Vulnerable. The total population of *Ipomoea polpha* subsp. *latzii* is well above this threshold, and is estimated (for the Tinfish-Low Level and Atatirk sub-populations) to be between 39,579 and 124,950 individuals. Although this estimate includes all individuals, rather than only reproductively mature plants, it greatly exceeds the D1 threshold. In addition, the recently located Long Range sub-population has not been included in this estimate, and is likely to contribute significantly to total population size and to the number of reproductively mature individuals. Under Vulnerable criterion D2, a taxon with an area of occupancy less than 20 km^2 is classified as Vulnerable. The Giant Sweet Potato has area of occupancy at least 26.7 km^2, and cannot be considered Vulnerable under this criterion. The Giant Sweet Potato does, however, fulfill the second element of criterion D2, as it is known from fewer than five localities. As the Giant Sweet Potato is a conspicuous taxon and is well known to the local Traditional Owners, there is a level of confidence that the plant is restricted to the three sub-populations described here. During consultation with the local people it seemed, anecdotally, that visiting locations where the Giant Sweet Potato occurs is an infrequent event, and some of the participants had not visited the area for more than ten years. The impact of harvesting the Giant Sweet Potato for food by the local Traditional Owners is considered to be extremely low, and highly unlikely to impact on the population size and persistence of this rare plant. The taxon should be classed as Vulnerable (IUCN 2008) under criterion D2 at a regional, national and global level.

Sampling methods and limitations

Although TEK has been recognized as a useful resource (Hanks 1984; Ross *et al.* 1994; Horstman & Wightman 2001) it has been utilized in few published studies (Huntington 2000; Horstman & Wightman 2001). Species currently coded as data deficient can be difficult to code under the IUCN guidelines. The limited number of localities of occurrence of the target species may be an artifact of sampling bias (either spatially or temporally), or the inherent cryptic nature of some taxa. Where the target species is known to local Aboriginal people such issues can be overcome, as they were for the Giant Sweet Potato. *Ipomoea polpha* subsp. *latzii* is culturally significant to the Anmatjerre people, and we were able to work with Traditional Owners who had direct knowledge of the distribution of the plant. Invaluable distributional information on the taxon was collected and used to target the field surveys. An additional and extensive sub-population was located by the Traditional Owners, contributing

significantly to the documented geographic range of the taxon, and to estimates of population size. The incorporation of TEK in the present study was especially important due to the lack of obvious environmental correlates that could be used to build a statistical distributional model.

Similar studies of rare plant species could benefit by consultation with local Traditional Owners. Rare taxa are more likely to be culturally important to local indigenous people when the organism (i) has a utilitarian value, such as for food or medicine; (ii) is large, abundant or unusual (Baker *et al.* 1993); (iii) is spiritually significant (Baker *et al.* 1993); or (iv) has a relationship to other important species, for example, if culturally significant animals browse or visit hollows (Nabhan 2000). For rare plant species with any of these four traits, cooperative research with indigenous communities can be developed to collect distributional and ecological data for the species. TEK is specifically referred to in the EPBC Act (1999) in section 3(1)(g) as follows: "The objects of this act are to promote the use of the indigenous people's knowledge of biodiversity with the involvement of, and in cooperation with, the owners of the knowledge." TEK is a resource too valuable to ignore in surveys of rare plants and animals.

Distance-sampling has rarely been used to estimate the abundance of plants, and it has remained largely within the domain of animal ecology (for example see Houndsome *et al.* 2005; Barlow & Taylor 2005; Novak *et al.* 2005). The distance-sampling method has been described by Buckland *et al.* (1993) as ideal for the assessment of plant populations. The assumptions of the methods, which must be met to produce robust estimates, are that: (i) target organisms do not display evasive movement, and, of course, plants always meet this assumption; (ii) the distance to the target organism can be measured with accuracy; and (iii) that every target organism occurring actually on the transect is detected. The detection probability of the *Ipomoea* plants was high due to their large size and clear visibility through the open woodlands. The method has several advantages over plot-based plant survey techniques, as every plant observed can be recorded, not just the individuals within quadrats or belt-transects. This is of particular importance for rare species as a larger number of individuals can be recorded, therefore improving estimates of abundance.

Further research on the Giant Sweet Potato

We recommend mapping the recently located Long Range sub-population of the Giant Sweet Potato, and it would be helpful to invite the Traditional Owners to participate. An on-going monitoring program for the taxon should be implemented, particularly to investigate the role of episodic periods of high rainfall on recruitment, and the potential impacts of wildfire and grazing on the Giant Sweet Potato.

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Fine-scale patchiness of burns in a mesic eucalypt savanna differs with fire season and Sorghum abundance

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Abstract

Canopy tree populations in the eucalypt savannas of northern Australia consistently show bottlenecks in the transition of young trees to the canopy layer. This is most likely due to frequent fires, where young trees are caught in a "fire trap", suffer topkill and regenerate from underground tissues year after year. Little is known of fire behaviour at the spatial scale of individual juvenile trees. This paper presents field measurements of small-scale, 10 cm (microsite), burn patterns and patch sizes following set fires in the early dry season, late dry season, and wet season. Fire treatments were repeated in plots dominated by a native annual grass (Sorghum) and in others with little or none of this grass. Both late dry season and wet season fires left few or no microsites unburnt, regardless of understorey type. With early dry season fire, however, understorey type made a difference: 47% of the microsites were left unburnt in plots with little or no Sorghum compared to only 5% in Sorghum-dominated plots. Further, the early dry season fire pattern was very patchy, resulting in both large and small areas of burnt vegetation. In Sorghum-dominated plots, more than half the patches were ≥ 10 m in size and only a third were < 3 m in size, whereas in plots with little or no Sorghum, 99% of burnt patches were < 10 m in size, and 41% were < 0.5 m in size. Thus, only a regime of early dry season fire with little or no Sorghum in the understorey creates potential "windows of escape" for juvenile trees. The study has implications for management of savanna trees by fire.

Introduction

A common finding in studies of canopy tree populations in the eucalypt dominated savannas of northern Australia is a demographic bottleneck in the transition of juvenile and sapling trees to the canopy layer (Werner 1986; Russell-Smith *et al.* 2003a; Werner *et al.* 2006; Lehmann *et al.* 2009; Williams 2009; Prior *et al.* 2010). Although more than one factor may be responsible for the bottlenecks, fire is most likely the

main cause. Frequent fires repeatedly kill the above-ground stems and leaves of young trees which have to be rebuilt from persistent underground tissues. In effect the young trees are caught year after year in a "fire trap" (Hoffmann *et al.* 2009), forming a pool of juvenile trees with their own population dynamics of "births" and "deaths" (Werner *et al.* 2006).

"Escape" of young trees from fire is critical for transition to canopy size in the northern savannas. If frequent fires are patchy at ground level, a juvenile tree might be able to escape being burnt altogether, and if this occurs repeatedly, over time it would be able to attain the height of the canopy layer where it could withstand all but the most intense fires. Although much is known about fire behaviour and patch sizes at the Landsat pixel size (30 m or more) (e.g. Russell-Smith *et al.* 1997), very little is known about fire behaviour or unburnt patches of vegetation at the spatial scale of individual juvenile trees (e.g., at 10 cm scale). Indeed, very little is understood in any of the world's savannas about the type and frequency of fires, and/or other factors such as rainfall, herbivory or understorey type, that permit or enhance the transition of a young tree to canopy size (see Midgley *et al.* 2010).

Although the seasonal timing of fire is known to affect survival and growth of established adult trees (Lonsdale & Braithwaite 1991; Williams *et al.* 1999; Werner 2005; Prior *et al.* 2006; Lehmann *et al.* 2009; Murphy *et al.* 2010), much less is known about the differential effect on juvenile trees, which ideally should include information about fire behaviour at the spatial scale of individual juveniles. Further, although total understorey biomass (Werner *et al.* 2006) and understorey type (Werner & Franklin in press) are known to affect survival of juvenile trees, potential differences in fire behaviour between grass and non-grass understoreys has not been reported previously.

Here, field measurements are presented of the fine scale pattern of ground-level burns by fires set in three different seasons (early dry, late dry, and wet) in two types of native understorey vegetation (high abundance of a common dominant annual grass, and little to none of this grass but a cover consisting mainly of perennial herbs).

Methods

Background: fire seasons and understorey types

Three major types of fires are commonly identified in the Top End of the Northern Territory, described relative to the very strong annual cycle of precipitation where 84% of 1,290-1,580 mm precipitation falls from December to March (Gill *et al.* 1987, 1996; Finlayson & von Oertzen 1996; Russell-Smith *et al.* 1997, 2003b; Williams *et al.* 1998; Andersen *et al.* 2003; Russell-Smith & Edwards 2006). The seasons are defined relative to recent weather, rather than calendar months, and thus vary in start and duration from year to year (Taylor & Tulloch 1985):

- early dry season: generally slow-moving, trunk-scorching, ground fires of low intensity; almost entirely set by humans, both historically by Aboriginal peoples and today by a wide range of land managers;
- late dry season: generally rapid-moving, canopy-scorching fires of high intensity as a consequence of greater leaf litter, drier fuels and more severe fire weather; mainly human set, but also caused by lightning; and
- early wet season: generally rapidly-moving, usually high-intensity fires, but may be lower intensity than late dry season fires depending on fuel, weather and the amount of recent rainfall. These fires are rare, sometimes started by lightning but more often by humans for management purposes.

As in many savannas, almost all fires are ground (not canopy) fires, but some may attain high intensities depending on the amount, type, and moisture content of grassy fuel. Large fuel loads (1-6 tonnes ha^{-1}: Cook *et al.* 1998; Williams *et al.* 1998, 1999; Bowman *et al.* 2007) are a consequence of the strongly seasonal rainfall and the subsequent drying of understorey plants. The main grassy component of fuel is a species of native annual sorghum, *Sorghum brachypodum* Lazarides (formerly *Sorghum intrans* F. Muell. and *Sarga intrans* (F. Muell.) Spangler) (Lazarides *et al.* 1991; Spangler 2003), commonly called Spear Grass or simply "Annual Sorghum". These grasses have single stems, often more than 2 m height; they set seed and die back at the end of the wet season, before almost all other native grasses and herbaceous forbs, and crumple into a perched, aerated, and easily ignited fuel by the time early dry season fires begin (Andrew & Mott 1983; Andrew 1986; Williams *et al.* 2003). In the absence of Sorghum (or introduced African grasses), the understorey is a mixture of smaller annual grasses, perennial grasses, forbs with rosettes and/or single to a few branching stems, and a scattering of small woody stems of trees and shrubs. All these plants delay browning off, or senescing, until the middle or late dry season (Williams *et al.* 2003).

Study area

The study was conducted in Kakadu National Park (KNP), specifically at the Kapalga Research Station (12°34'S, 132°22'E). The geomorphology, soils, climate, and vegetation of the Kakadu region are detailed by Taylor & Dunlop (1985), Press *et al.* (1995) and Finlayson & von Oertzen (1996), and those of Kapalga by Andersen *et al.* (2003).

The study was conducted in 1988 and 1989 in the southern half of Kapalga, where feral water buffalo had been excluded for six years after a period of heavy grazing for some 30 years prior to their removal. In September 1987, a high-intensity fire had burnt all study sites, so little previous-year litter remained in 1988. All study sites had similar woody canopy cover and size structure of mature trees. This study pre-dated, and was not part of, the Kapalga fire experiment (Andersen *et al.* 2003).

Both early dry season and late dry season fire treatments were set up in Compartment J (see map of Kapalga in Andersen *et al.* 1998), approximately 20 km^2 in size. For the early

dry season fire treatments, eight different plots, each 30 x 30 m (total area 7,200 m^2) were mapped. Four were dominated by Sorghum (40-80% ground cover) (hereafter "Sorghum plots") and four had between 0 and 20% ground cover of Sorghum (hereafter "plots with little or no Sorghum"). Similarly, the late dry season fire treatment consisted of eight different plots, each 30 x 30 m (total area 7,200 m^2), four with Sorghum and four with little or no Sorghum.

For wet season fire treatments, ten plots, each 20 x 50 m (total area 10,000 m^2) were established, six dominated by Sorghum and four with little or no Sorghum. The plots were located adjacent to Compartments E, F, G, H, L, and P (see Andersen *et al.* 1998).

For the unburnt comparisons, eight plots, each 20 x 50 m (total area 8,000 m^2), were set up, half in Compartment C with ground cover dominated by Sorghum and half in Compartment S with little or no Sorghum.

For all fire treatments, care was taken to pair the Sorghum and little or no Sorghum plots wherever possible, and pairs were sited across the perceived gradual topographic gradient so that any differences would not be attributable to location on the gentle slope.

Understorey vegetation

The projective ground cover (%) of herbaceous species and woody stems < 2 m height was recorded in each of the 34 study plots in the early dry season of 1988 prior to the first fire treatment, using 20 one-metre square subplots within each plot (five randomly placed subplots along four 30-metre transects). Further, more than 3,000 juvenile trees were individually marked and monitored for three years (Werner & Franklin in press).

Prescribed fires

The wet season, early dry season, and late dry season fires were lit in late December 1988, late May 1989, and late September 1989, respectively. Fires were set using drip cans and multiple ignition sites across a transect, upslope of relevant compartment sections, on a day with little wind. They were set more than 100 m away from the plots so that whereas the fires were set as "fronting" fires, they behaved in a more realistic, natural landscape pattern by the time they arrived at the monitored plots. After the fires, the heights of charring (dark discolouration of bark) and scorching (withering of leaves due to heat) and ground-level patchiness of the fires were assessed along four 30 m transects within each plot. The fires were judged to be "low intensity" or "high intensity" based on the occurrence and height of scorching and charring (Gill *et al.* 1987; Williams *et al.* 1998, 1999).

Patchiness of burns

Within one month of each fire, a fine-scale, ground-level assessment of the area burnt was made. Along the upslope boundary (or eastern boundary if there was no discernible slope) of each 30 m study plot, four transects (at the 6 m, 12 m, 18 m, and 24 m location) were run across the plot to the opposite side. Along each transect, the distance along the

ground of "burnt" or "unburnt" vegetation was recorded to the nearest 10 cm. Where a burnt patch intersected one plot boundary, only the width of the patch within the plot was recorded. In some cases the burnt patch intersected both ends of the 30 m plot boundary, in which case the patch size was recorded as > 30 m.

A chi-square test was used to examine differences in burn patchiness between Sorghum and little or no Sorghum plots after early dry season fire. The number of degrees of freedom was calculated as (6 patch sizes –1) (2 grass types –1) = 5. No further analysis was conducted on fires set at other seasons as nearly all ground was burnt regardless of understorey type.

Total area burnt by patch size

Extrapolation of patch size frequencies to the total area of various size patches per hectare was performed for early dry season fires only, using the linear measurements of patch sizes, calculating area (assuming a circle) of each patch, and standardizing the sums to one hectare (10,000 m^2). These calculations are estimates of further differences between Sorghum and little or no Sorghum plots.

Results

Pre-fire understorey composition

All plant species were natives; there were no exotic plants in the study plots (Table 1). In Sorghum plots, Annual Sorghum was by far the most abundant species, 40-80% projected ground cover (mean = 70%), compared to plots with 0-20% (mean = 7%) cover of Sorghum. Further, total ground cover was generally higher in Sorghum plots (50-85 % total cover) compared to plots with little or no Sorghum (30-65% total cover). Conversely, ground cover of herbaceous dicotyledons tended to be less in Sorghum plots than plots with little or no Sorghum (< 10% and > 20% per plot, respectively). The ground cover of the main forb species, (herbaceous dicotyledons with single or multi-stems and/or basal rosettes, eg, *Mitrasacme* spp., *Stylidium* spp., and *Spermacoce* spp.) tended to be relatively greater in plots with little or no Sorghum than in Sorghum plots (all species collectively, means = 22% vs. 15%, respectively) (Table 1).

Fire intensity and total area burnt

Early dry season fires were of low-intensity with char heights < 2 m, and scorch heights < 3.5 m; the canopy leaves of the tallest trees were not scorched. The late dry season and wet season fires were both of high intensity. These fires charred tree trunks at heights 2-7 m above ground level and scorched and/or burnt the leaf canopy.

With early dry season fires, grass abundance affected the percentage of 10 cm microsites burnt. In stands with little or no Sorghum, only 53% of the microsites were burnt compared to nearly all (95%) microsites in Sorghum plots (Figure 1). In late dry season fire plots, literally all of the ground surface area was burned, regardless of grass

abundance, so essentially all juvenile trees experienced fire. Similarly, grass abundance made little difference in the wet season fire plots, where 99% and 93% of the microsites experienced fire in Sorghum vs. little or no Sorghum plots, respectively (Figure 1).

Table 1. Understorey vegetation, as percentage projective ground cover, summarized across all plots with high abundance of Sorghum vs. little or no Sorghum, at the end of growing season (May) prior to the setting of fires. The individual species named were frequent and appeared in at least half of the plots. All species are natives; there were no exotic plants in the study plots.

Species or group	Habit	Sorghum plots	Little or no Sorghum plots
Sorghum brachypodum Lazarides & other sorghums	Annual grass	40-80% (mean = 70%)	0-20% (mean = 7%)
Pseudopogonatherum contortum (Brongn.) A. Camus	Annual grass	7%	9%
Other annual grasses (collectively)*	Annual grass	4%	2%
Alloteropsis semialata (R. Br.) Hitchc.	Perennial grass	5%	9%
Heteropogon triticeus (R. Br.) Stapf. and *H. contortus* (L.) P. Beauv. ex Roem. & Schult.	Perennial grass	8%	5%
Chrysopogon latifolius S. T. Blake and *C. fallax* S. T. Blake	Perennial grass	3%	< 1%
Other perennial grasses (collectively)**	Perennial grass	< 1%	< 1%
Dicotyledonous herbs (collectively) (basal rosettes, single or multi-stemmed)***	Annual and perennial forbs	15%	22%
Woody stems; shrubs and trees < 2 m height (collectively)	Perennial woody plants	10%	10%
Overall vegetation percentage cover		**50-85%**	**30-65%**

* Other annual grasses include *Panicum mindanaense* Merr., *Setaria apiculata* (Schribn. & Merr.) K. Schum., and *Thaumastochloa major* S. T. Blake, among others. ** Other perennial grasses include *Mnesithea rottboelhoides* (R. Br.) de Konig & Sosef., among others. *** Dicotyledonous forbs include species of *Stylidium* (Stylidiaceae), *Mitrasacme* (Loganiaceae), and *Spermacoce* (formerly *Borreria*) (Rubiaceae), among others.

Patchiness

Early dry season fire was generally patchy, resulting in both large and small areas of burnt and unburnt vegetation. Furthermore, the patterns of burnt/unburnt patches differed with abundance of Sorghum (X^2 = 68.61; df =5, P < 0.001). In Sorghum plots, the patches of burnt ground tended to be large, but in plots with little or no Sorghum, there

was a finer mosaic of smaller burnt patches (Figure 2). For example, in Sorghum plots, more than half the patches were ≥ 10 m in size (14% were ≥ 30 m) and only a third of burnt patches were < 3 m in size. In plots with little or no Sorghum almost all (99%) the burnt patches were < 10 m in size, 41% being less than 1 m in size (Figure 2).

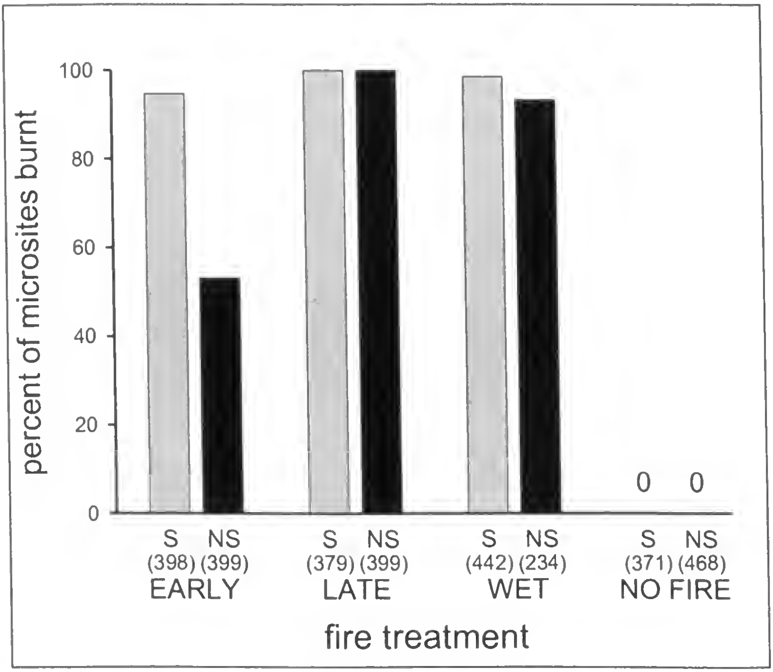

Figure 1. The percentage of total area (percentage of microsites at 10 cm each) burnt in each seasonal timing of fire treatment and Sorghum density. S = Sorghum plots; NS = plots with little or no Sorghum. Numbers refer to the total number of juvenile trees (< 200 cm height) in each study plot.

On a per hectare basis, the estimated area left unburnt in early dry season fire was 500 m^2 for Sorghum vs. 4,700 m^2 for plots with little or no Sorghum. Based on frequency distributions of patch size categories <0.5 m, 0.5-<3 m, 3-<10 m, 10-<20 m, 20-<30 m and >30 m (Figure 2), the estimated total area burnt per hectare in Sorghum plots was 10 m^2, 20 m^2, 240 m^2, 1,900 m^2, 2,860 m^2 and 4,470 m^2. By contrast, in plots with little or no Sorghum, the estimated total area burnt per hectare in the same patch size categories was 45 m^2, 475 m^2, 3,800 m^2, 970 m^2, 0 m^2 and 0 m^2, respectively.

The patchiness of late dry season fires was similar in Sorghum and little or no Sorghum plots, with essentially all ground burnt and all patch sizes ≥ 30 m. The wet season fire also created mainly large patches, nearly all being ≥ 30 m.

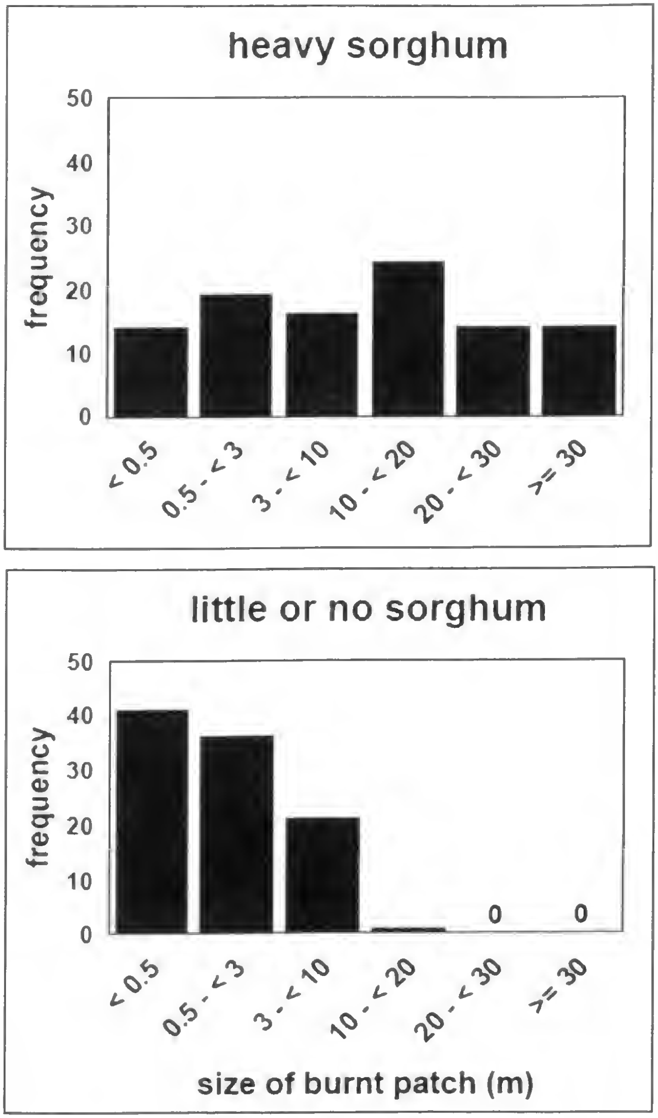

Figure 2. The frequency of burnt patches by size (linear distance (m) along transects), after early dry season fires in Sorghum plots and in plots with little or no Sorghum in the understorey.

Discussion

The fine-scale pattern of burns in early dry and late dry season fires is consistent with casual observations by field researchers and has not been documented previously in eucalypt savanna woodlands. In nearby sandstone heath vegetation, fine-scale patterns of patchiness relative to different fire regimes were examined by Price *et al* (2003), who reported 64% vs. 84% total area burnt in early dry season vs. late dry season fires, respectively, and with patch sizes generally < 10 m in both seasons. In sandstone country, unburnt patches were strongly associated with rockiness. However, in the absence of rocks, 100% of the area was burnt in late dry season fires (Price *et al.* 2003), yielding relative differences between fire seasons comparable to ours in the savanna woodlands.

Late dry season fires create a "scorched earth" with little probability that any juvenile tree would escape being burnt, regardless of abundance of Sorghum. Werner & Franklin (in press) report that 100% of juvenile trees (< 200 cm height) were burnt to the ground in the late dry season fire. These resprouted only from lignotubers but generally regained previous height the following year. Further, approximately 20% of saplings (200-500 cm height) were burnt to the ground but original height was not regained the following year (Werner & Franklin in press). Given the relatively slow average rates of height growth of small juvenile trees (Werner *et al.* 2006), it is very doubtful that many, if any, young trees would be able to grow out of the "fire trap" into a size large enough to withstand further fires, wherever late dry season fires occur more often than every 7-10 years.

By contrast, early dry season fire patterns differ with the type of understorey, and this can have different consequences for smaller juvenile trees. In Sorghum plots, where all microsites are burnt and the frequency distribution of patch sizes is relatively uniform, it is not surprising that nearly 100% of those juvenile trees that were < 100 cm height in these plots, and 50% or more of juveniles 100 to 200 cm height, suffered complete topkill and subsequently resprouted only from lignotubers (Werner & Franklin in press). High frequency of early dry season fires in Sorghum will not only enhance Sorghum abundance, but also greatly reduce the probability that juvenile trees will grow into the canopy. Alternatively, in areas with little or no Sorghum, where only about half the total area is burnt and where about half the burn patches are small (most likely reflecting lower flammability and or heterogeneity of the plant growth forms) only about 50% of those juvenile trees that were under 150 cm in height in these plots were topkilled and resprouted from lignotubers, and about 60% of young trees 150-500 cm height showed no first-year effects of early dry season fire (Werner & Franklin in press). This combination, early dry season fire and little or no Sorghum understorey, provides the highest probability that a young tree will avoid being burnt, and hence, the greatest chance it can eventually grow sufficient height to escape, and/or develop bark thick enough, to withstand subsequent fires, thus making the transition into the canopy.

The burn pattern for wet season fires shows at least one possible outcome, but we cannot say that it is most representative, as wet season fire behaviours would vary greatly from year to year depending on vagaries in the timing and amount of early rainfall events. The onset of the wet season can vary by some 10 weeks on the calendar (Taylor & Tulloch 1985). Our fires, set in December, were at the beginning of the wet season, and perhaps it is no surprise that results are similar to late dry season fires. More than 85% of juveniles suffered topkill with subsequent resprouting from lignotubers (Werner & Franklin in press).

The biological impact of wet season fires may be very different from that of late dry season fires for other reasons. For example, the smallest juvenile trees (< 100 cm height) are physiologically active during the wet season, but are generally leafless and dormant during late dry season fires, and any disturbance or removal of biomass may produce very different outcomes with respect to juvenile tree dormancy, survival and growth (Werner *et al.* 2006).

The differences in phenology between the two types of understorey, along with differences in total biomass and growth form that may carry fire differently, may help explain why fine-scale fire patterns are different between the two understorey types when burnt early in the dry season, but do not differ in late dry season or wet season fires. Annual Sorghum is among the earliest plants to complete its seasonal cycle, producing dry fuel prior to early dry season fires, whereas smaller annual grasses, perennial grasses and forbs remain green much longer, well into the middle or late dry season.

The degree to which grassy vs. non-grassy understoreys affect fine-scale burn patterns of fires set in different seasons remains unexplored in savannas across the world. Comparative information on burn patterns at a scale of juvenile trees could be important in developing a general understanding of bottlenecks in transitions between seeds or seedlings and canopy trees, which are a common feature on every other continent where this topic has been studied (Platt *et al.* 1988; Grace & Platt 1995; Chidumayo & Frost 1996; Scholes & Archer 1997; Gilliam & Platt 1999; Hoffmann 1999; Higgins *et al.* 2000; Bond & Midgley 2001; Midgley & Bond 2001; Hoffmann & Moreira 2002; Hoffmann & Solbrig 2003; Sankaran *et al.* 2004; Gardner 2006; Bond 2008; Hoffmann & Haridasan 2008; Hoffmann *et al.* 2009; Midgley *et al.* 2010). Specifically, comparisons of the role of the understorey in mitigating the fine-scale burn pattern of fires at different seasons in the mesic savannas of eastern and southern Africa could be very instructive. In contrast to the annual single-stemmed grasses of northern Australia, these African savannas are dominated by perennial tussock grasses (Bond & Van Wilgen 1996).

Implications for management

In northern Australia, early dry season fires are commonly lit by managers to reduce the probability of a late dry season fire occurring in the same year. I suggest that

consideration be given to the understorey when setting these fires, since the presence of Sorghum greatly reduces the patchiness of ground-level burn and hence reduces the chance that individual juvenile trees will escape topkill, whereas lack of Sorghum yields a much patchier burn and hence increases the chance that young trees will avoid being burnt back. In sites where Sorghum is abundant, instead of the usual early dry season fire, the most appropriate action would be a wet season fire set soon after Sorghum seeds have germinated, which can eliminate Sorghum for several years (Press 1987; Lazarides *et al.* 1991; Cook *et al.* 1998; Miles 2003).

Unfortunately, some areas of northern Australia now have large stands of introduced African grasses (e.g. Gamba Grass) which brown off later in the dry season than does Sorghum, while increasing fuel loads up to seven times and thereby changing fire behaviour and potential impacts on biota (Rossiter *et al.* 2003; Setterfield *et al.* 2010). This has been the case in pine savannas of south-eastern North America where other introduced grasses flourish (Platt & Gottschalk 2001). It is not unreasonable to expect that tree regeneration will be greatly inhibited in those northern Australian savannas where African grasses have become established, as has been demonstrated in the cerrados of Brazil where an invasive grass inhibits tree regeneration (Hoffmann & Haridasan 2008).

Conclusion

From this study of fine-scale patchiness of fire in different seasons and Sorghum abundances, I suggest the following as a working hypothesis with respect to the transition of young trees to the canopy in the Australian savannas: under a regime of early dry season fires and with an understorey of native non-Sorghum species (excluding introduced grasses), a significant number of microsites or areas will escape being burnt, creating potential "windows of escape" for some juveniles which eventually grow to sapling and canopy sizes. Conversely, whenever repeat fires occur in other seasons and wherever the understorey is Sorghum, the probability of a juvenile tree growing into the canopy is extremely low.

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Birdlife of Mickett Creek: factors influencing frequency of occurrence and detection

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Abstract

Over a five-year period 82 bird species were recorded during diurnal visits to the Mickett Creek area near Darwin. Frequently recorded species were generally those that were resident (hence present all year round), were moderately to highly abundant, and vocalised regularly. Species with loud or highly penetrating calls and vocally active species may have been recorded more often than other birds of similar abundance. Infrequently recorded species included seasonal visitors, particularly dry season migrants and birds associated with seasonal wetlands, and discreet species that are presumably resident but are rarely detected because of secretive habits and vocalisation characteristics. Nocturnal species were infrequently flushed during the day, but are known from the area from nocturnal surveys. Habitat types, seasonal distribution of water, food resources, and movement patterns of birds affect species composition at a local scale. It is concluded that numerous surveys over many years are required to obtain a comprehensive avifaunal species inventory for bushland sites in monsoonal northern Australia.

Introduction

Birds of the Top End of the Northern Territory comprise a diverse range of widely distributed species of the Torresian Zone, a small number of endemics, and a number of seasonal visitors (Morton & Brennan 1991). The avifauna of woodlands at a local scale consists partially of resident birds, supplemented with a range of visitors attracted to resources (Woinarski & Tidemann 1991; Franklin & Noske 1999), nomads, and species undergoing seasonal movements. Crawford (1972) provided the first comprehensive annotated list of birds of the Darwin region, including 254 species, based on five years of observations. Crawford noted the influence of seasonal movements, habitat selection, differences between subcoastal and inland avifaunal elements, and inter-annual population variability. Thompson (1978, 1988) described the common species of the Darwin suburbs and the Darwin area generally, including information on habitat and seasonality. The seasonal abundance of select groups has been described from a site near Darwin (Thompson 1982, 1984; McKean 1986), and there is some published material concerning food resources (Franklin & Noske 1999, 2000) and the role of vegetation type (Woinarski *et al.* 1988) on bird species

composition in monsoonal northern Australia. However, there is a paucity of site-specific survey data for areas near Darwin that examine frequency of occurrence in relation to the various factors that influence bird species presence and abundance.

In the course of preparing an inventory of species from a site, several factors determine how frequently a bird will be detected and recorded by an observer. At a fundamental level, the *presence* of a bird will be influenced by whether suitable habitat exists within the geographical distribution of the species (see Blakers *et al.* 1984; Barrett *et al.* 2003). Birds tend to occupy particular structural formations of vegetation, for example woodland or grassland. They may also be influenced by vegetation type, as delimited by the dominant plants, e.g. *Melaleuca* forest, eucalypt woodland. The extent and pattern of habitat type within the study site should, therefore, affect presence and abundance of bird species, and availability of resources within the habitat will also play a role (Wiens 1989). A subset of species will be present seasonally because of migratory or nomadic tendencies, and others will move locally. Even those species that are present throughout the year may be more or less active (and hence obvious), particularly in regard to calling, at various times of the year.

The second major consideration is the *detectability* of the species by an observer. Detectability is the probability that a bird will be recorded, and is dependent on whether the bird is audible or visible to the observer during the survey period. This is influenced by the behaviour of the individual bird, including the frequency and intensity (loudness) of calling, and whether it is obvious and thereby is detected. Many birds are secretive or cryptic, and may avoid the observer. Abundance will affect the probability of a species being recorded, and this will be influenced by aggregation, flocking and clumped distributions. The second component of detectability is the ability of the observer to discern and identify either the call (which may vary considerably) or the bird by sight. This is largely affected by familiarity with the avifauna of the region including knowledge of calls, but also the survey procedure adopted (Recher 1984; Saffer 2001). Lastly, time of day is likely to affect bird activity. It is generally accepted that birds are most active in the early morning and also (but less so) in the late afternoon. However, there are no published data in relation to the diurnal activity patterns of the birdlife of monsoonal northern Australia, and, at certain times (e.g. when it is cloudy) birds may be active at any time of day. The response to diurnal weather fluctuations and season in this regard is also not at all understood.

Here I provide frequency of occurrence information for bird species recorded from the Mickett Creek bushland site near Darwin, and examine some of the factors that influence the frequency with which the various components of the avifauna were observed. The study provides an insight into the species found in the area and serves as a basis for more systematic studies of functional ecological relationships, behaviour, breeding biology and habitat preferences.

Methods

The Mickett Creek site (12°24'39"S 130°56'37"E) is on the edge of suburban Darwin, Northern Territory, in the locality of Knuckey Lagoon, Shire of Litchfield. The site is on vacant Crown Land and is accessed via Brandt Road. It is part of an area of bushland, between the northern suburbs of Darwin and the city of Palmerston, which extends to the coast. Vehicular and walking tracks traverse the site, and several areas of bare soil and reduced vegetative cover exist as a result of past and on-going anthropogenic disturbance, including regular use by motorbike riders and off-road vehicles. To the north is the Mickett Creek Shooting Complex, which (aside from the cleared shooting ranges) has relatively undisturbed bushland, and to the west is Holmes Jungle. The site is approximately 7 km from the coast at Shoal Bay, but less than 4 km from mangrove estuarine habitats in the lower reaches of Mickett Creek.

In the monsoonal tropics the distribution of vegetation communities at a local scale is largely determined by position in the landscape and duration of inundation (Taylor & Dunlop 1985; Wilson & Bowman 1987; Cowie *et al.* 2000). The site comprises a freshwater low-lying section and associated savanna surroundings, and can be divided into three vegetation communities: upland savanna; mixed woodland intergrade habitats; and lowland seasonally wet or inundated drainages and damplands. The savanna open woodland is dominated by *Eucalyptus tetrodonta* and *Eucalyptus miniata* with *Erythrophleum chlorostachys* and the fully deciduous species *Terminalia ferdinandiana.* It is fairly typical of savanna woodlands (Brock 2001), with various shrubs and small trees including *Buchanania obovata, Livistona humilis, Planchonia careya* and *Acacia* spp. It is mapped as subcoastal open-forest (*E. miniata* and *E. tetrodonta* over *Sorghum*: Wilson *et al.*, 1990; Fox *et al.*, 2001) and is similar to the *Eucalyptus* open-forest of Wilson and Bowman (1986, 1987). In the seasonally wetter and less well-drained intergrade habitats, *Pandanus spiralis, Lophostemon lactifluus, Grevillea pteridifolia* and *Petalostigma pubescens* are more prevalent. The vegetation corresponds to the *Pandanus*/*Grevillea* and *Lophostemon*/*Eucalyptus* mixed open-forest of Wilson and Bowman (1987), and the mixed forest habitat of Crawford (1972). Low-lying seasonal creek and dampland habitats support *Carallia brachiata, Banksia dentata, Pandanus spiralis* and scattered *Corymbia polycarpa. Grevillea pteridifolia* generally occurs in mixed associations, and *Melaleuca viridiflora* dominates in seasonally inundated sites where it may occur as monospecific stands. Sedges and herbs grow in the wetter areas, with some patches dominated by *Dapsilanthus spathaceus,* and aquatics are evident in the wet season. Vines are obvious in the early wet season and mistletoe occurs particularly on *Melaleuca* spp. and *Grevillea pteridifolia.* Important flowering species (Franklin & Noske 2000) include *E. miniata, E.tetrodonta, C. polycarpa, G. pteridifolia* and *Melaleuca* spp.

Portions of the low-lying, seasonally inundated areas are natural regeneration from sand mining in the late 1970s and into the 1980s. Much of the habitat dominated by *Melaleuca viridiflora* appears to be regrowth. *Carallia brachiata* is becoming dominant in some low-lying regrowth patches, and a formation approaching a low closed-forest

has developed. In drier areas *Calytrix exstipulata* is characteristic of regeneration. Some soil expanses in heavily used areas remain devoid of vegetation. Of the invasive plant species at the site the most widespread is Perennial Mission Grass *Pennisetum pedicellatum* which is patchy in places and dominant in others, but in general is absent from wetter areas.

The environment in the wet and dry season is strongly contrasting. During the wet there is significant inundation of low-lying areas, creeks form and water flows. Flows diminish in the first part of the dry season (May to July) and all surface water usually disappears by September. Unusually for an area of bushland close to the city, the site was unburnt in most years. However, much of the upper savanna portion was burnt in the late dry season of 2008, and a patch of intergrade vegetation was burnt in July 2003.

Visits to the Mickett Creek area were initiated in May 2003, although not for the specific purpose of recording birds. A period was spent gaining familiarity with bird calls and becoming acquainted with the layout of the study area prior to keeping records. From January 2004 to August 2009 birds were recorded during diurnal visits to the site on 60 occasions. The site has been visited on numerous other occasions, particularly at night, but frequency data were included only where dedicated records were kept and birding was a focus of the visit. The survey procedure involved traversing the area on foot, using the network of tracks but also involving regular forays into the bush. Although a defined route was not followed, the portion of the site surveyed most frequently was approximately five hectares in area. In various instances exploratory excursions were made to new parts of the site. The aim during each visit was to record all species encountered. Although birds were often seen, in the great majority of cases birds were identified on the basis of calls. Unusual calls or unknown calls were investigated and the birds identified by sight.

Waterbirds that occur at nearby Knuckeys Lagoon that were observed overhead (e.g. Brolga *Grus rubicunda*), or that were heard as they passed over the site (e.g. Wandering Whistling-Duck *Dendrocygna arcuata*), were not included in the list for the site. Other birds seen overhead including lorikeets, diurnal birds of prey, and all passerines (including White-breasted Woodswallow and Tree Martin) were incorporated on the basis that they utilise the habitat either directly or while foraging overhead. Other species that were included were waterbirds using seasonally inundated areas, and Magpie Goose that were roosting in trees. The frequency data is based on the 60 diurnal surveys. Additional, incidental species recorded at other times have been noted in Table 1.

The average duration of visits was 70 minutes, and visits varied from 40 to 140 minutes. Most surveys were 60 ± 15 minutes. Slightly over half of the visits were in the morning (start time before 1000 hours), 30% were in the middle of the day (1000-1630), and the remainder were in the afternoon (1700 onward), with some of these last surveys continuing until dark. Visits were made in all months of the year (although

spread over the five years), with from three to seven visits per month, and most months having four or five visits.

Table 1. Bird species, frequency of observation, and habitat use at the Mickett Creek study site. Frequency (F) is the number of visits (out of 60) on which the species was recorded during diurnal surveys (- = incidental record). Species that had been recorded by 20 and 40 visits are indicated with an X. Habitat: S = savanna; I = mixed woodland (intergrade); and D = low-lying drainages and damplands. Other: N = recorded also during nocturnal surveys; n = flushed at night; o = observed overhead or in passage; and * indicates a nesting record. The family sequence follows Christidis and Boles (1994); names have been updated according to Christidis and Boles (2008).

Common Name *Species*	20	40	F	Habitat	Other
Non-Passerines					
Brown Quail *Coturnix ypsilophora*	X	X	2	S	
Magpie Goose *Anseranas semipalmata*		X	4	SD	N *o*
Radjah Shelduck *Tadorna radjah*	X	X	13	D	
Green Pygmy-goose *Nettapus pulchellus*			-	D	
Straw-necked Ibis *Threskiornis spinicollis*		X	1	D	
White-bellied Sea Eagle *Haliaeetus leucogaster*		X	2	D	
Whistling Kite *Haliastur sphenurus*	X	X	18	SID	
Black Kite *Milvus migrans*	X	X	10	SID	o
Black-breasted Buzzard *Hamirostra melanosternon*		X	1	S	o
Letter-winged Kite *Elanus scriptus*			1	S	o
Brown Goshawk *Accipiter fasciatus*		X	2	SI	
Collared Sparrowhawk *Accipiter cirrhocephalus*		X	1	S	
Common Greenshank *Tringa nebularia*		X	3	D	
Bush Stone-curlew *Esacus magnirostris*	X	X	3	SD	N
Masked Lapwing *Vanellus miles*	X	X	3	D	
Bar-shouldered Dove *Geopelia humeralis*	X	X	43	SID	n
Peaceful Dove *Geopelia striata*	X	X	51	SID	n
Diamond Dove *Geopelia cuneata*			1	S	
Pied Imperial Pigeon *Ducula bicolor*	X	X	1	D	
Red-tailed Black Cockatoo *Calyptorhynchus banksii*	X	X	26	SI	
Sulphur-crested Cockatoo *Cacatua galerita*	X	X	27	SID	
Little Corella *Cacatua sanguinea*	X	X	12	SID	
Red-winged Parrot *Aprosmictus erythropterus*	X	X	26	SI	
Northern Rosella *Platycercus venustus*	X	X	1	S	
Rainbow Lorikeet *Trichoglossus haematodus*	X	X	48	SID	o
Varied Lorikeet *Psitteuteles versicolor*	X	X	7	S	o
Pheasant Coucal *Centropus phasianinus*	X	X	12	SID	
Eastern Koel *Eudynamys orientalis*		X	7	ID	
Brush Cuckoo *Cacomantis variolosus*	X	X	14	SID	
Barking Owl *Ninox connivens*			2	D	N
Tawny Frogmouth *Podargus strigoides*		X	2	SID	N
Large-tailed Nightjar *Caprimulgus macrurus*			-	D	N
Blue-winged Kookaburra *Dacelo leachii*	X	X	29	SID	
Forest Kingfisher *Todiramphus macleayii*	X	X	38	ID	
Sacred Kingfisher *Todiramphus sanctus*		X	1	S	

Table 1 continued

Common Name *Species*	20	40	F	Habitat	Other
Rainbow Bee-eater *Merops ornatus*	X	X	45	SD	*
Dollarbird *Eurystomus orientalis*	X	X	14	SID	
Passerines					
Red-backed Fairy-wren *Malurus melanocephalus*	X	X	35	SI	
Weebill *Smicrornis brevirostris*	X	X	51	S	
Striated Pardalote *Pardalotus striatus*	X	X	37	SID	*
White-throated Gerygone *Gerygone albogularis*	X	X	3	SI	
Little Friarbird *Philemon citreogularis*	X	X	18	SID	
Silver-crowned Friarbird *Philemon argenticeps*	X	X	15	SID	
Helmeted Friarbird *Philemon buceroides*		X	2	ID	
Blue-faced Honeyeater *Entomyzon cyanotis*	X	X	11	SI	
White-throated Honeyeater *Melithreptus albogularis*	X	X	48	SI	
White-gaped Honeyeater *Lichenostomus unicolor*	X	X	45	SID	
Rufous-banded Honeyeater *Conopophila albogularis*	X	X	25	DI	*
Yellow-throated Miner *Manorina flavigula*	X	X	3	S	
Bar-breasted Honeyeater *Ramsayornis fasciatus*	X	X	4	D	
Brown Honeyeater *Lichmera indistincta*	X	X	45	SID	
Dusky Honeyeater *Myzomela obscura*			5	ID	
Banded Honeyeater *Cissomela pectoralis*			1	D	
Lemon-bellied Flycatcher *Microeca flavigaster*	X	X	46	ID	*
Grey-crowned Babbler *Pomatostomus temporalis*	X	X	47	SID	
Rufous Whistler *Pachycephala rufiventris*			1	S	
Grey Whistler *Pachycephala simplex*			1	D	
Spangled Drongo *Dicrurus bracteatus*	X	X	8	ID	
Magpie-lark *Grallina cyanoleuca*	X	X	21	SD	
Leaden Flycatcher *Myiagra rubecula*	X	X	7	SD	
Willie Wagtail *Rhipidura leucophrys*		X	2	ID	
Northern Fantail *Rhipidura rufiventris*	X	X	11	ID	
Black-faced Cuckoo-shrike *Coracina novaehollandiae*	X	X	5	S	
White-bellied Cuckoo-shrike *Coracina papuensis*	X	X	50	SI	
Varied Triller *Lalage leucomela*	X	X	10	ID	
White-winged Triller *Lalage sueurii*			2	ID	
Figbird *Sphecotheres viridis*	X	X	4	SI	
Yellow Oriole *Oriolus flavocinctus*	X	X	31	SID	
Olive-backed Oriole *Oriolus sagittatus*	X	X	3	SI	
White-breasted Woodswallow *Artamus leucorhynchus*	X	X	17	SID	o
Little Woodswallow *Artamus minor*			1	D	
Pied Butcherbird *Cracticus nigrogularis*	X	X	5	SI	
Grey Butcherbird *Cracticus torquatus*	X	X	27	S	
Torresian Crow *Corvus orru*	X	X	33	SID	
Great Bowerbird *Ptilonorhynchus nuchalis*			3	SI	
Chestnut-breasted Mannikin *Lonchura castaneothorax*			1	D	
Long-tailed Finch *Poephila acuticauda*	X	X	27	D	*
Masked Finch *Poephila personata*		X	9	D	
Double-barred Finch *Taeniopygia bichenovii*	X	X	39	SID	*
Crimson Finch *Neochmia phaeton*	X	X	7	D	
Mistletoebird *Dicaeum hirundinaceum*	X	X	39	SID	
Tree Martin *Petrochelidon nigricans*		X	4	SD	o

Results

A total of 82 species was recorded from the site after 60 visits, including 45 passerines and 37 non-passerines (Table 1). The number of species recorded was 48, 55, 69 and 80 (two additional species were recorded incidentally) after 12, 20, 40 and 60 visits respectively. The number of species continued to increase gradually after 30 visits (Figure 1). A full list of species recorded from the site with current scientific names is provided in Table 1.

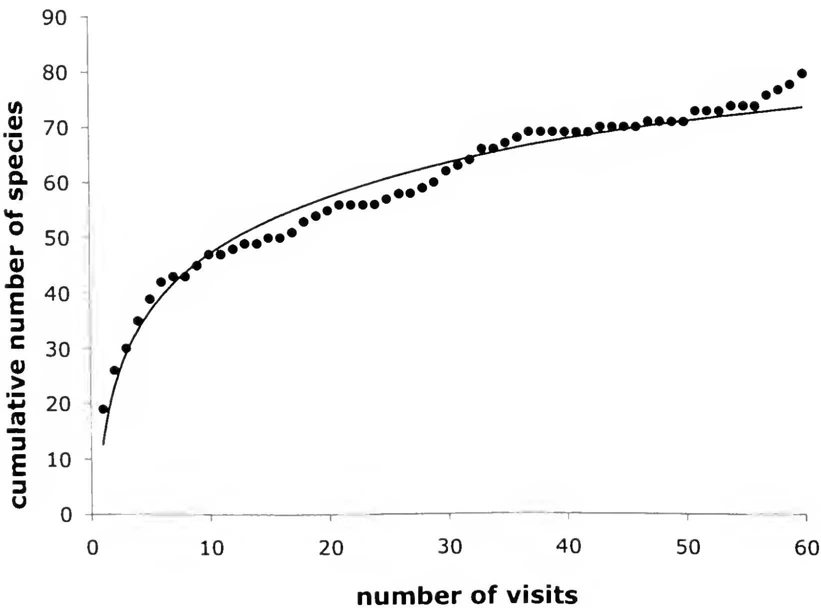

Figure 1. Species accumulation curve (points) for bird species recorded at Mickett Creek. The logarithmic curve has the form $y = 14.95\ ln\ (x) + 12.63$.

The number of species recorded during a visit ranged from 11 to 36, the average number recorded was 20 and the median was 19. On 15 occasions, 25 or more species were recorded; these surveys were generally in the morning (start time before 0830 h) and were always (with one exception) of more than an hour duration. Families represented by the greatest number of species (in parentheses) were the honeyeaters (Meliphagidae 12), diurnal raptors (Accipitridae 7), finches (Passeridae 5), pigeons and doves (Columbidae 4), and parrots (Cacatuidae 3 and Psittacidae 4). Five waterbirds and four nocturnal species were recorded.

After 60 visits, 11 species (4 non-passerines and 7 passerines) had been recorded on 40 or more occasions: Bar-shouldered Dove, Peaceful Dove, Rainbow Lorikeet, Rainbow Bee-eater, Weebill, White-throated Honeyeater, White-gaped Honeyeater, Brown Honeyeater, Lemon-bellied Flycatcher, Grey-crowned Babbler and White-bellied Cuckoo-shrike (Table 1). These were amongst the most regularly recorded species at 12, 20 and 40 visits, and species composition of the most frequently recorded species changed little over time. In all, 18 species can be categorised as common (recorded on 31 or more occasions) and 21 species as moderately common (11-30 occasions; Table 1). The majority of species were observed on ten or fewer occasions (Figure 2).

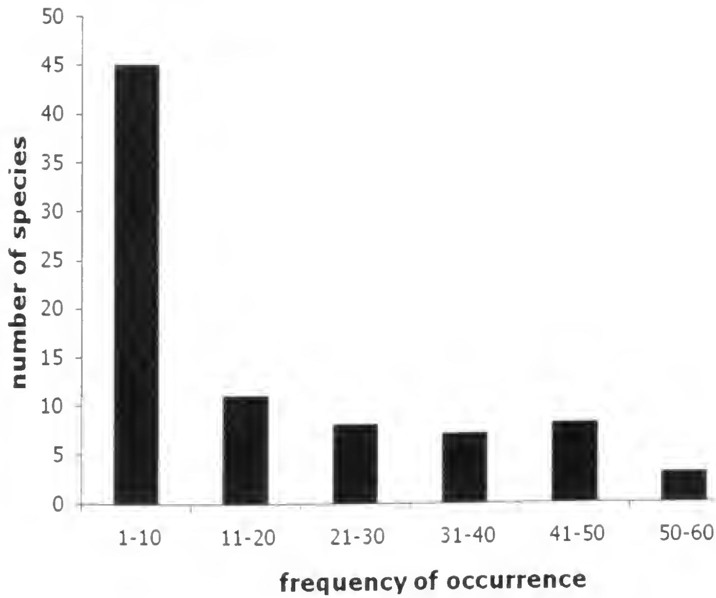

Figure 2. Frequency of occurrence of bird species at Mickett Creek after 60 visits.

Infrequently recorded species included several raptors and a mix of other irregular visitors to the site (Table 2). Three waterbirds were infrequent wet season visitors and Magpie Goose was observed on four occasions. Green Pygmy-goose was an incidental record. Six species are infrequent dry season visitors to the location (Table 2), and in addition Black-faced Cuckoo-shrike and Tree Martin were recorded on five and four occasions respectively. Several nocturnal species have been flushed infrequently during diurnal transects, and Large-tailed Nightjar was recorded only at night (Table 1).

Table 2. Infrequently recorded bird species (recorded three times or less during diurnal surveys) including seasonal visitors to the Mickett Creek locality and nocturnal species. Refer to Table 1 for frequency of observation. Status is based on seasonality of records from the site and information in Crawford (1972), Press *et al.* (1995), and Noske and Brennan (2002).

Resident or nomad	Dry season visitor
Brown Quail	Straw-necked Ibis
White-bellied Sea-Eagle	Diamond Dove
Black-breasted Buzzard	Sacred Kingfisher
Letter-winged Kite	White-winged Triller
Brown Goshawk	Olive-backed Oriole
Collared Sparrowhawk	Little Woodswallow
Masked Lapwing	
Northern Rosella	**Wet season visitor**
White-throated Gerygone	Green Pygmy-goose
Helmeted Friarbird	Common Greenshank
Yellow-throated Miner	Pied Imperial Pigeon
Banded Honeyeater	
Rufous Whistler	**Nocturnal species**
Grey Whistler	Bush Stone-curlew
Willie Wagtail	Barking Owl
Great Bowerbird	Tawny Frogmouth
Chestnut-breasted Mannikin	Large-tailed Nightjar

Discussion

Approximately a third of the bird species known from the Darwin region (Crawford 1972; Thompson 1978), over a quarter of the species recorded from Kakadu (Press *et al.* 1995), and approximately half of the species known from Litchfield National Park (Griffiths *et al.* 1997) were recorded from the Mickett Creek site. The greater area and diversity of habitats, including escarpments, coastal habitats and extensive freshwater wetlands, support a range of additional species in the other areas (Morton & Brennan 1991; Press *et al.* 1995). With the notable absence of Partridge Pigeon *Geophaps smithii*, bird species were similar to the 44 species recorded from five or more quadrats at Litchfield National Park (Woinarski *et al.* 2004). The forest and woodland birds are similar to those recorded by Woinarski *et al.* (1988) at nearby Howard's Peninsula. In contrast, the site supports relatively few of the birds associated with monsoon forest habitats. For example, Orange-footed Scrubfowl *Megapodius reinwardt*, Rainbow Pitta *Pitta iris* and Green-backed Gerygone *Gerygone chloronotus* were not present, and Grey Whistler was recorded only once. Figbird and Pied Imperial Pigeon were infrequently recorded, but are common in Darwin suburbs (Thompson 1978; pers. obs.) where tropical vegetation in well-watered gardens promotes flowering trees and fruiting palms. Species common both at Mickett Creek and in the suburbs of Darwin included

White-gaped Honeyeater, Rufous-banded Honeyeater, Double-barred Finch and Bar-shouldered Dove. Common grassland birds (e.g. Golden-headed Cisticola *Cisticola exilis*) were not observed, although potentially suitable habitat exists in the lower portions of the site during the wet season.

The most frequently recorded species, and indeed most of the species that were recorded on greater than 50% of visits (18 species, or 22% of the total; Table 1) were generally resident (Crawford 1972; McKean 1986; Thompson 1988; this study), moderately to highly abundant, and vocalise regularly. The relatively few nesting records were all of common or moderately common species (Table 1). In species rich families (raptors, parrots, finches, honeyeaters) there were usually one or two common species, while others were irregularly recorded, suggesting that these groups comprise both resident and visiting species.

Plant species and vegetation structure are determining features of the environment of birds (Macarthur & Macarthur 1961; Recher 1969; Ford 1989). Many birds of tropical northern Australia have wide habitat preferences (Morton & Brennan 1991), and utilise a range of foraging heights (Brooker *et al.* 1990). While most species utilised more than one habitat at the site, many were partially restricted to savanna or lowland areas. Typical savanna birds included Weebill, White-throated Honeyeater, White-bellied Cuckoo-shrike, Red-backed Fairy-wren, Grey Butcherbird and Red-winged Parrot. Lemon-bellied Flycatcher was abundant in patches of *Melaleuca* swamp. The vegetation in the wetter parts of the site is reverting to monsoon forest, and supports Yellow Oriole, Spangled Drongo, Rufous-banded Honeyeater, Varied Triller and Large-tailed Nightjar. Enhanced plant diversity and greater structural diversity of mesic habitats leads to greater avifaunal diversity (Noske & Brennan 2002), and may facilitate the survival of additional forest species in the future.

Food (particularly nectar) availability is known to enhance diversity (Ford 1989; Woinarski & Tidemann 1991) and local abundance (Franklin & Noske 1999) of birds in savanna environments. Major attractants in the area were the blossom of *Grevillea pteridifolia* (Friarbirds, small honeyeaters), *Eucalyptus miniata* (Rainbow Lorikeets and honeyeaters) and *Melaleuca viridiflora* (Rainbow Lorikeet, Friarbirds, small honeyeaters). There is a range of nectarivores in monsoonal northern Australia (Franklin & Noske 2000), and a diversity of flowering plants with potential to provide nectar sources throughout the year, but with a peak in the dry season (Franklin & Noske 1999; Brady 2009). Some species were regularly observed at blossom (e.g. Dusky Honeyeater, Brown Honeyeater), but probably all observed nectarivores are insectivorous to some extent. Mistletoe flowers and fruit are important to the Mistletoebird and were accessed by some of the honeyeaters.

Waterbirds, including Radjah Shelduck, Greenshank and Green Pygmy-goose, were occasionally attracted to temporary wetland habitats. A juvenile Sea-Eagle was also recorded in one year near a seasonally inundated lagoon. Finches tended to be more noticeable in the dry season, and as the water receded, they sought out remnant pools.

Long-tailed Finch, Masked Finch, Crimson Finch and Chestnut-breasted Mannikin were mainly recorded adjacent to water. Crawford (1972) noted a number of bushbird species that are more common, or only found, near water; proximity to water may partially explain the regular occurrence of Forest Kingfisher at the site.

Several species were seasonal visitors to the site and the Top End (Crawford 1972; Thompson 1978; Press *et al.* 1995). These species were recorded less frequently than most resident birds (Table 2). Eastern (Common) Koel is absent from the Darwin region in the dry season (Thompson 1982) and was relatively infrequent at Mickett Creek. Dollarbird is a fairly regular migrant (Thompson 1984) and was recorded in most years, being noticeable particularly in the buildup. Rainbow Bee-eater is a partial migrant, a species in which some birds are resident but others migrate (Chan 2001). This species was observed nesting in August, similar to other locations in Darwin (pers. obs.). Thompson (1984) noted a dry season peak in abundance of the Rainbow Bee-eater, possibly due to the presence of wintering birds from southern Australia, where they are strictly summer visitors. Some migratory species may consist of several sub-populations, including intracontinental migrants, overwater migrants to New Guinea and Indonesia (Beehler *et al.* 1986), and birds resident in northern Australia.

Dry season visitors including Black-faced Cuckoo-shrike and White-winged Triller (McKean 1986), Tree Martin and Little Woodswallow were recorded infrequently (Table 2). Seasonal reversal of prevailing wind direction may be an important factor in movement of birds to and from the tropical north. Black-faced Cuckoo-shrike, White-winged Triller, Tree Martin, Black Kite and White-breasted Woodswallow move from inland and may reach the coast or further afield, including southern New Guinea (Blakers *et al.* 1984; McKean 1986). Diamond Dove and Yellow-throated Miner are comparatively rare near the coast, but are relatively common in the southern half of Darwin region (Crawford 1972), and occur all year at Coomalie (R. Noske, pers. comm.). This could be regarded as movement to better-watered northern regions in the dry season, but Crawford (1979) viewed this phenomenon as a wet season migration from Darwin region due to 'improvements in conditions in the interior'. The arrival and departure dates of migrants are variable between years (Crawford 1972; Thompson 1982), and factors that induce migratory and nomadic movements in Australian arid zone and savanna birds remain poorly understood.

Calling associated with breeding or other seasonal activity means that some, and possibly all species are more likely to be detected at certain times of year. The Brush Cuckoo is particularly vocal in the wet season but is present throughout the year (Thompson 1982). Yellow Oriole tends to be more vocal during the buildup, and Striated Pardalote is more vocally active in the dry season when it constructs burrows to breed. Crawford (1972) noted that the Striated Pardalote makes a soft trill call in the wet, when it is much less conspicuous. It is difficult to ascertain if this species is a seasonal visitor or quiet resident. This is one of several species that are assumed to be

resident, but when they are vocally inactive they may easily be missed. There is a desperate need for studies to ascertain if species such as these are indeed sedentary.

Calling activity is dependent on time of day (Keast 1994), and this may affect the number of species recorded during a survey. Some species call early in the morning (e.g. Blue-winged Kookaburra), most call more frequently in the morning as part of the dawn chorus (e.g. Brown Honeyeater, White-gaped Honeyeater, Lemon-bellied Flycatcher, Bar-shouldered Dove, etc.), and some species call throughout the day (e.g. Weebill, White-throated Honeyeater, Brown Honeyeater). There is also generally a late afternoon peak. Further research is required to determine how temporal patterns of calling activity affect species recorded during (often brief) avifauna surveys. During rainy weather or in windy conditions, few species were recorded because activity and calling is reduced or ceases and birds are less conspicuous.

Visibility to an observer and characteristics of the call, including both audibility and regularity of calling, will influence the likelihood of detection of a bird species. Detailed knowledge of calls is important (Remsen 1994), especially where a species produces different types of vocalisations (e.g. juvenile, territorial, alarm and contact calls). Preliminary investigations to ensure familiarity with the bird calls at a site should be carried out prior to initiating detailed surveys. Birds with loud or highly penetrating calls (including Pheasant Coucal, Blue-winged Kookaburra, Red-tailed Black Cockatoo, Sulphur-crested Cockatoo, Bush Stone-curlew and Yellow Oriole) can be heard from a distance, so that they are more likely to be detected. In contrast, Leaden Flycatcher, Dusky Honeyeater, Bar-breasted Honeyeater, Red-backed Fairy-wren and Brown Goshawk can be very discreet. Nocturnal species were observed opportunistically at night, but were flushed rarely or not at all during the day; their cryptic plumage and immobility may often mean that they are not recorded although they are present.

After five years new bird species were still being added periodically to the Mickett Creek list (Figure 1), and it is doubtful whether all species have been recorded from the site. Indeed, nine new species were added in the last year of observations. The high proportion of rarely recorded species resulted in a long upward slope to the asymptote (Thompson & Withers 2003), and is suggestive of a variety of immigrant and transitory species visiting the area (Pielou 1977, p.289). Extrapolation of a logarithmic fit to the species accumulation data (generated in Excel; $r^2 = 0.96$) indicates that the accumulated total after 200 visits would approach 92 species. Based on the Chao 1 method (cited by Colwell & Coddington 1994), which incorporates the contribution of rarely recorded species, the calculated lower bound is 96 species. Numerous surveys over many years are required to obtain a comprehensive species inventory of all core and wandering species, particularly in tropical environments (Parker 1991; Remsen 1994). The majority of species were recorded on fewer than ten occasions, and 13 species were recorded only once. This underlines the importance of long-term studies of avifaunal communities. The addition of alternative methods for

censusing birds, (e.g. mist-netting and playback), would likely further increase the total for the area (Parker 1991).

Acknowledgements

Knowledge of the birds of the Darwin region and surrounds was enhanced by discussions with Richard Noske. Plant species were identified in many cases with the assistance of staff at the NT Herbarium. Charles Darwin University provided facilities and transport. Don Franklin provided valuable comments on the draft manuscript. Thanks are due to various companions on visits to Mickett Creek over the years.

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The Leaden Flycatcher (female illustrated) was a less common inhabitat of savannas and drainage lines at Mickett Creek. (Con Foley)

The Diamond Dove was a rare, dry season visitor to savanna habitat at Mickett Creek. (Con Foley)

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Home range and movement patterns of an Estuarine Crocodile *Crocodylus porosus*: a satellite tracking pilot study

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Abstract

The number of Estuarine Crocodiles *Crocodylus porosus* in the Northern Territory, Australia is increasing. This has led to an increase in interaction with humans and livestock. Whilst there have been a number of studies on the distribution and movement of crocodiles in Australia, little has been recorded detailing movement patterns, and less evaluating the technical effectiveness of employing satellite tracking technology on this species. We attached an Argos satellite transmitter to a 4.2 m male Estuarine Crocodile captured in the Adelaide River, approximately 100 km east of Darwin, Northern Territory, Australia. During the six month study period (July to December 2005), the crocodile showed definite signs of home range fidelity, staying within a Minimum Convex Polygon of 63 km^2 and a 95% kernel area of 8 km^2. The average daily movement was 5.9 km day^{-1} with increased movement during the month of December. A high percentage of useable locations (65%) were received from the Platform Terminal Transmitter, with an increased number of location readings occurring between 2000 and 0700 hours. Given the aggressiveness of this species and the hostile environments in which they live, the Argos system is a useful method for tracking their movement. The results of this study have provided preliminary information improving our understanding of the home range and behaviour of a large male crocodile.

Introduction

The Estuarine or Saltwater Crocodile *Crocodylus porosus,* is endangered in many parts of the world. In the Northern Territory, Australia, however, numbers of *C. porosus* have increased markedly over the last 35 years. During the 1950s and 60s, crocodile numbers in this area decreased severely due to an intensive skin trade, leading to non-hatchling population estimates in the early 1970s of as low as 3,000. The import and export of crocodile skins and products was banned in 1971 which effectively ended this exploitation (Messel & Vorlicek 1986). Subsequently, crocodile numbers rebounded sharply and by 2001 populations were estimated at more than 75,000 (Webb 2002).

Caldicott *et al.* (2005) estimate that crocodiles in Australia have been responsible for 62 unprovoked attacks on humans between 1971 and 2004, with 63% of these taking place in the Northern Territory. They link an increasing incidence of crocodile attacks in northern Australia to recovery of the crocodile population and to increase in housing, agricultural and recreational activities adjacent to, or within, crocodile habitats. It is believed that as interactions with this once low numbered and endangered species begin to increase, the public's sympathy with conservation measures may begin to decline. This situation places more pressure upon management agencies to continue developing species management plans that balance conservation concerns for the species, public needs, and budgetary restrictions of conservation agencies.

Programs are currently underway to manage increasing crocodile numbers, for example, public education initiatives, 'problem crocodile' removal, warning signs at high-risk swimming areas, and sustainable use such as wild egg harvest (Leach *et al.* 2009). An understanding of crocodile home range and movement patterns could provide information for improving these programs and be a basis for developing sound management strategies. Unfortunately, aggressiveness of the species and the hostile environments in which they live make crocodiles difficult to study using conventional methods. Thus, until recently, virtually nothing was known about the movements of Estuarine Crocodiles (Caldicott *et al.* 2005; Letnic & Connors 2006).

Prior to 2001, all data on movement of Estuarine Crocodiles were obtained using mark and recapture methods (Webb & Messel 1978). The first telemetry tracking study of the Estuarine Crocodile was undertaken by Kay (2004a) who used Very High Frequency (VHF) technology to carry out land-based tracking of crocodiles between October 2001 and May 2003 in the Cambridge Gulf region of Western Australia. Following this, Brien *et al.* (2008) used VHF to track five males and eight females during 2003 and 2004 in Lakefield National Park, Northern Queensland. Mark and recapture methods provided baseline information on the movements of Saltwater Crocodiles and VHF telemetry improved our understanding of home range and seasonal movement patterns. However, there are a number of shortfalls associated with these techniques including high recurrent costs due to the intensive fieldwork as well as the risk of potentially modifying the animal's behaviour due to observer presence (Kenward 2001). More recently, Read *et al.* (2007) captured and tracked three large male Estuarine Crocodiles in northern Queensland using Argos telemetry, demonstrating the potential this technology can have for remotely obtaining large amounts of long range movement data.

As no satellite tracking movement studies have previously taken place on this species in the Northern Territory, this pilot study aimed to contribute preliminary biological information related to crocodile movement within an area near Darwin, as well as to test the attachment of a transmitter and evaluate the effectiveness of satellite technology for monitoring this species. Results will be used to enhance management

plans and public safety programs and for future research on the use of this technology on this species.

To enhance our understanding of crocodile movement we deployed a satellite transmitter to monitor a crocodile in the Northern Territory, Australia. Specific objectives were to 1) quantify home range size 2) identify areas of high use 3) describe daily and seasonal movement patterns 4) identify correlation between movement and meteorological variables and finally 5) evaluate the technical performance of the transmitter under field conditions. This fifth objective will aid in the interpretation of biological results to help determine whether the technology functioned efficiently enough to underpin crocodile management decisions.

Methods

The research area was the Adelaide River, located approximately 100 km east of Darwin, Northern Territory (Figure 1). We chose this river because of its known crocodile population and the belief that some members of this population move out into the Darwin Harbour area (Mike Letnic, Parks and Wildlife Service Northern Territory, pers. comm.). Based on a high number of recreation activities that take place in the Darwin Harbour and an increased incidence of human interaction, crocodile movement in this area was of particular interest.

Platform Transmitter Terminals (PTTs) send a signal via the Argos® satellite system (CLS, Ramonville Saint-Agne, France). The PTT used was the Kiwisat 101, designed and customized by Sirtrack (Sirtrack Wildlife Tracking Solutions; Havelock North, New Zealand) with the help of Queensland Parks and Wildlife Service (QPWS). This system consists of polar orbiting satellites located 800 km above the earth equipped with Ultra High Frequency receivers. Each time the satellite passes over a PTT, it has approximately 10 minutes to calculate its location using the Doppler effect. Each location point is classified and assigned one of several Location Classes (LC), depending on the accuracy of the location estimate. In this study, we assumed the standard deviation of positional error in latitudinal and longitudinal axes to be 150 m for LC 3, 350 m for LC 2, 1 km for LC 1 and >1 km for LC 0 (Collecte Localisation Satellites 2010). When three or fewer messages are received by the satellite, the accuracy levels are LC A & B (no estimation accuracy) or LC Z (invalid location). Only locations with an Argos specified accuracy of <1 km (LC 3, 2 and 1) were used for analysis.

The tracking unit measured 120 mm (L) x 32 mm (W) x 24 mm (H); it weighed 300 g, well below the recommendation of no more than 3-5% of the body weight of the animal (Kenward 2001). The PTT was powered by a single lithium C cell battery and set to a duty cycle of 24 hours on followed by 96 hours off; it was on for approximately 34 hours a week, giving it an expected life of around 450 days. The PTT had other battery preservation features, including a salt water switch activated by

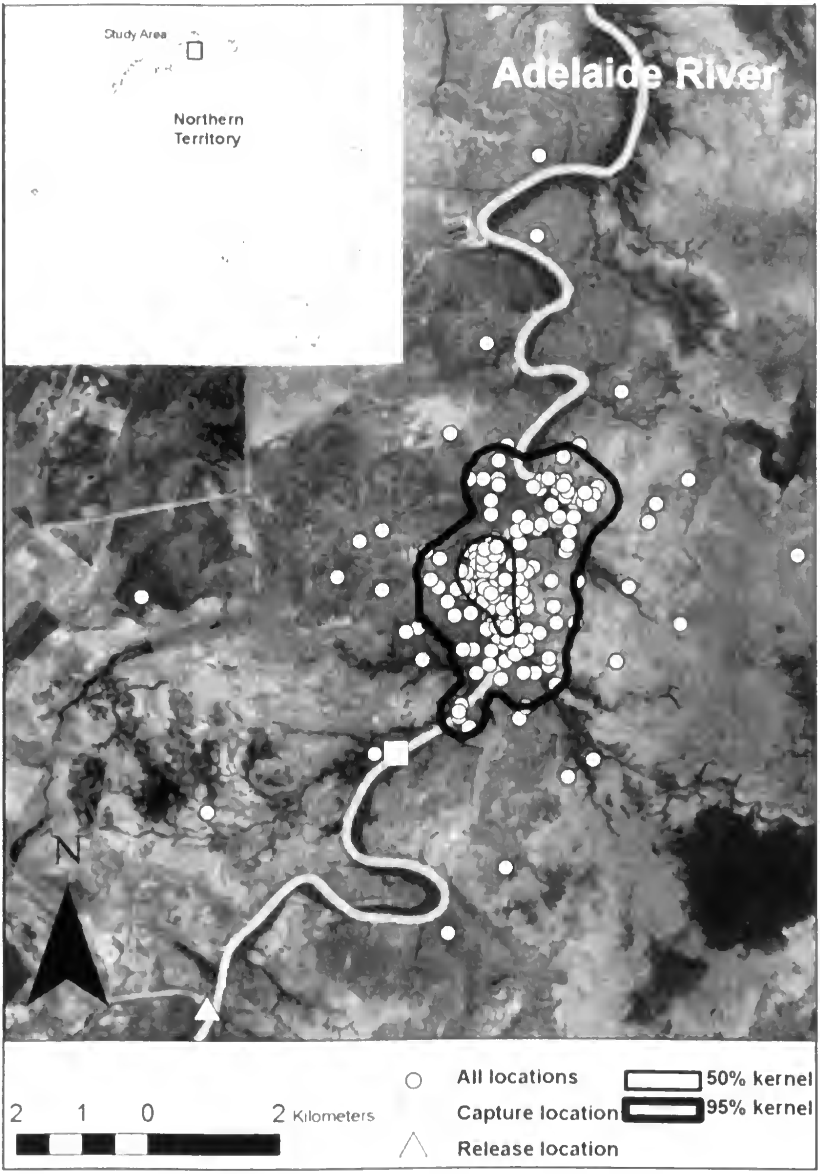

Figure 1. Satellite image map showing LC 3, 2 and 1 locations of *Crocodylus porosus* in the Adelaide River area, approximately 100 km east of Darwin, between 13 July and 31 December 2005. The capture location was *c.* 80 km inland from the mouth of the river. Accuracy of locations is LC 3 ± 150 m, LC 2 ± 350 m and LC 1 ± 1 km.

salinity levels. This prevented transmission when the transmitter was submerged in water, or it was out of water for longer than 4 hours, and allowed transmission to resume upon resurfacing or re-entering the water. A VHF transmitter was also incorporated into the PTT so the device could be found using conventional radio tracking if necessary. Argos tracking technology was chosen for this research because of its ability to provide remote location data to help understand the behaviour of a dangerous animal living in an inaccessible area at a reasonable cost. The specific unit selected for this research was chosen because of its size, shape, durability and energy efficiency.

We captured a 4.2 m male crocodile at approximately 2300 h on 12 July 2005. The capture location was 80 km from the Adelaide River estuary. Experienced crocodile handlers from the Parks and Wildlife Service, Northern Territory (PWSNT) captured the selected crocodile using the live capture skin harpoon method (DEWHA 2003). It is generally agreed that this is a quick, efficient and low stress method of capturing different sized crocodiles. The harpoon consists of a 3 m pole with a three-pronged detachable harpoon with barbed points attached to a hand spool of parachute cord. The preferred target is the dorsal area of the neck which is very muscular and relatively free of bones. Once harpooned, the crocodile was initially allowed to pull away and then slowly retrieved in much the same way as catching a fish. The crocodile was then brought to the side of the boat where a noose was placed over its neck, its snout bound and it was sedated with Valium®. Because the crocodile was too large to pull into the boat, it was secured to the side and taken to an attachment/release location on the river bank approximately 8 km further upstream from the capture location (Figure 1). Here the eyes were covered to reduce visual stimulation, the rear legs were bound alongside the body with nylon webbing, the harpoon was removed and the PTT was attached.

The attachment team, led by Mark Read from the QPWS, secured the transmitter using a variation of the Winston Kay method (Kay 2004b). This method has been tried and tested on a number of tracked crocodiles in northern Queensland. After capturing and restraining the crocodile, the nuchal shield area was cleansed using a chlorhexidine scrub and rinsed with 70% ethanol. A local anaesthetic (lignocaine) was used to anaesthetize the nuchal shield area. This was administered using multiple intra-muscular injections of 1.5 to 3 ml which were placed around the base of the nuchal shield. After approximately 20 minutes the anaesthetized area was stimulated to check for a reaction from the crocodile. When no reaction was observed a portable drill fitted with a sterilized 3 mm drill-bit was used to drill two holes into each of the four large nuchal shields. The transmitter was then placed between the nuchal shields, and two pre-cut lengths of plastic coated stainless steel wire (100 kg breaking strain) were used to secure the transmitter by threading the wire through the holes and then through the attachment loops fixed to the lateral face of the transmitter (Figure 2). The wire was then secured by using standard lead crimps that degrade over time to release the transmitter and wire.

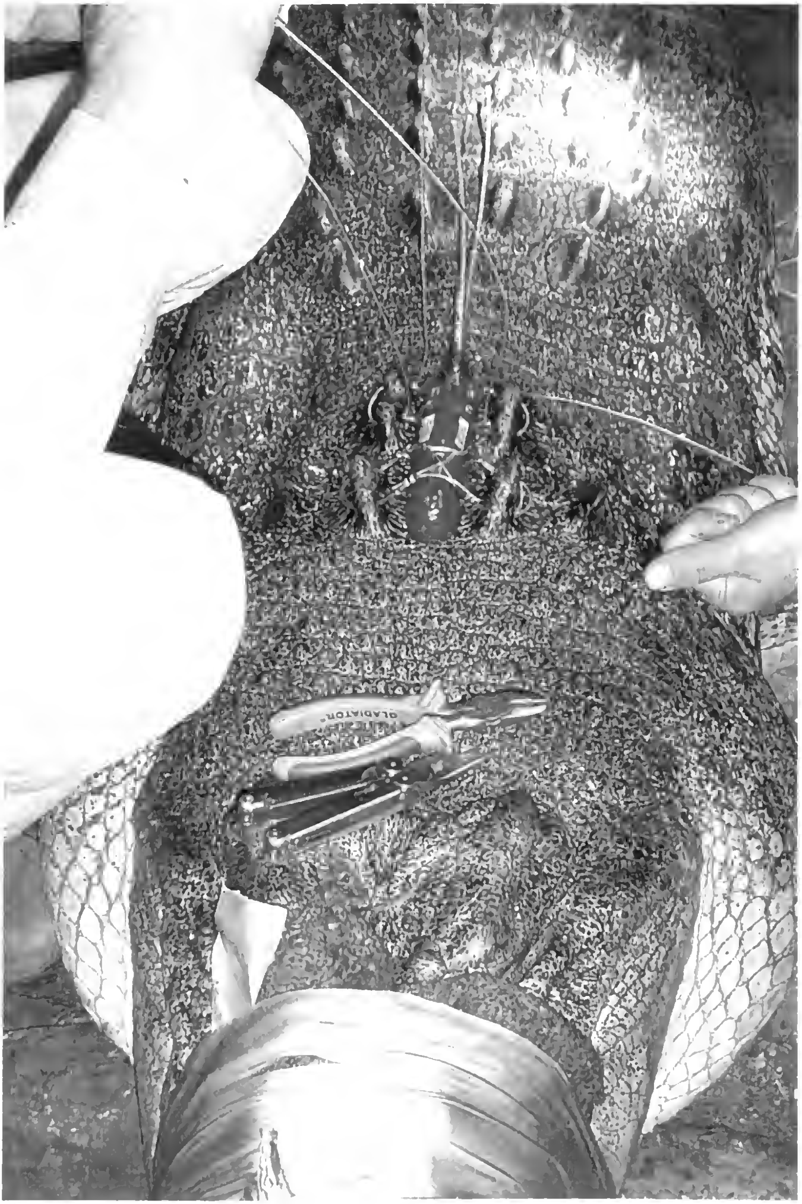

Figure 2. Image showing the study animal (*Crocodylus porosus*) during the attachment of the Platform Terminal Transmitter. The plastic coated stainless steel wire is being threaded through the holes in the nuchal shields. (Derek C. Robertson)

Prior to release, the rear legs and snout were unbound and the eyes uncovered. The crocodile was visually monitored for signs of disorientation and other abnormal behaviours for approximately one hour. After this period it turned and crawled back into the river.

This study was expected to provide data for at least one year (July 2005 to July 2006), but transmission ceased after six months. Movement during the dry and build up to the wet seasons was therefore covered. Between July 2005 and December 2005, locations of the crocodile were downloaded using an Argos telnet connection and maps were generated using a Geographic Information System (GIS) (ArcGIS® ArcMap® 9.2, Environmental Systems Research Institute, Redlands, California, USA). Data locations were recorded in latitude/longitude WGS84, and transformed to Universal Transverse Mercator (UTM) zone 53 S for analysis. Location time was converted from Greenwich Mean Time to Darwin local time, which was a difference of + 9½ hours. Local GIS layers for the study area were supplied by the Geographic Information Systems Group from PWSNT.

The area of the home range, Minimum Convex Polygon (MCP) and kernel were calculated using the Animal Movement Analyst extension to ArcView (Hooge & Eichenlaub 1997). MCP estimators are thought to overestimate space use (Kenward 2001), but they were used here to enable comparison with other studies as well as to indicate the maximum area potentially required by the crocodile. A kernel home range, utilising the 95% probability contour, was used as a second measure to reduce outlier bias. The least-squares cross validation procedure was used to determine the smoothing parameter. Minitab® 15.1.30.0 (© 2007 Minitab Inc., State College, Pennsylvania, USA) was used for all statistical analysis. Unless otherwise noted, all means are expressed as the mean (± s.d.).

Distance was calculated using the Postdist function within Microsoft Excel 2003 and, to allow for the four-day gap between each data download period, was calculated using consecutive locations within each 24 hour download period only. We assumed straight-line movement between consecutive points. Speed was calculated in a similar way using consecutive locations in the same data download period, and was the ratio of distance travelled (metres) to the time interval (seconds).

The temperature (°C) used was obtained from the transmitter at the time of each location. Rainfall (mm), humidity (%) and air pressure (hPa) were obtained from the Australian Bureau of Meteorology (BOM) using the nearest remote weather station to the study area, the Middle Point AWS (#14041) located at (12.605°S, 131.2983°E). Rainfall comprised precipitation during the 24 hours prior to 0900 h local time on the day of the location; this was then assigned to crocodile locations obtained on that day. Humidity and air pressure were both taken at 0900 and 1500 h each day and assigned to locations depending on the time of the location. Locations falling between midnight and midday were assigned the 0900 reading, and locations falling between midday and midnight were assigned the 1500 reading.

Results

Performance of the technology

The PTT was tested prior to attachment and confirmed to be operating correctly. Locations of all class types were received from 13 July 2005 to 31 Dec 2005 (n = 305 locations over 172 days). LC 3 constituted 27% (83) of total locations, LC 2 22% (67), and LC 1 16% (48). The remaining 35% (107) of locations were designated as LC 0, A, B or Z. We obtained an average of nine locations per 24 hours, of which an average of six were useable (LC 3, 2 and 1).

The transmitter, with its pre-programmed duty cycle, was activated at 0020 h on 13 July 2005. The transmitter performed well, sending in 24 hours of data every fifth day without fail, which equated to 34 download periods or full days of tracking. A higher number of LC 3, 2 and 1 locations were received between the hours of 2000 and 0700 than at other times (Figure 3). The time of the first location obtained during each 24 hour download period ranged from 0026 to 1706 h, with an average time of 0356 h. The last location obtained during each 24 hour period ranged from 1845 to 0017 h, with an average time of 1923 h. The average time difference between two consecutive locations within a 24 hour period was approximately 6 hours, ranging from 1 to 13 hours.

We identified a slightly negative relationship (r^2 = -0.038) between the number of acquired locations and time as the PTT approached the end of its theoretical lifespan, but this was not significant. A similar, but also non-significant relationship was seen with battery voltage levels over time (r^2 = -0.025).

Crocodile movements

Successive positions from the satellite data allowed us to estimate the crocodile's home range (Figure 1). Using all LC 3, 2 and 1 locations (n = 198), the MCP home range was 63 km^2, the 95% kernel home range was 8 km^2 and the midstream linear range was 24 km. A high use area calculated using the 50% kernel home range is also shown in Figure 1. This equates to an area of approximately 1 km^2.

The mean daily distance moved was 5.9 ± 3.2 km day^{-1} with a maximum daily distance of 13 km day^{-1}. This maximum daily distance was observed during the month of September, although most movement occurred during December (Figure 4). The mean distance moved between two consecutive locations was 1.2 ± 1.2 km. The maximum distance was 7.8 km, calculated over a time period of almost four hours in the early hours of 26 September 2005. The mean speed between consecutive locations was 2 ± 1.2 km h^{-1}, with the fastest speed of 3.6 km h^{-1} recorded on 26 October 2005 (4.5 km covered between 2149 and 2308 h.).

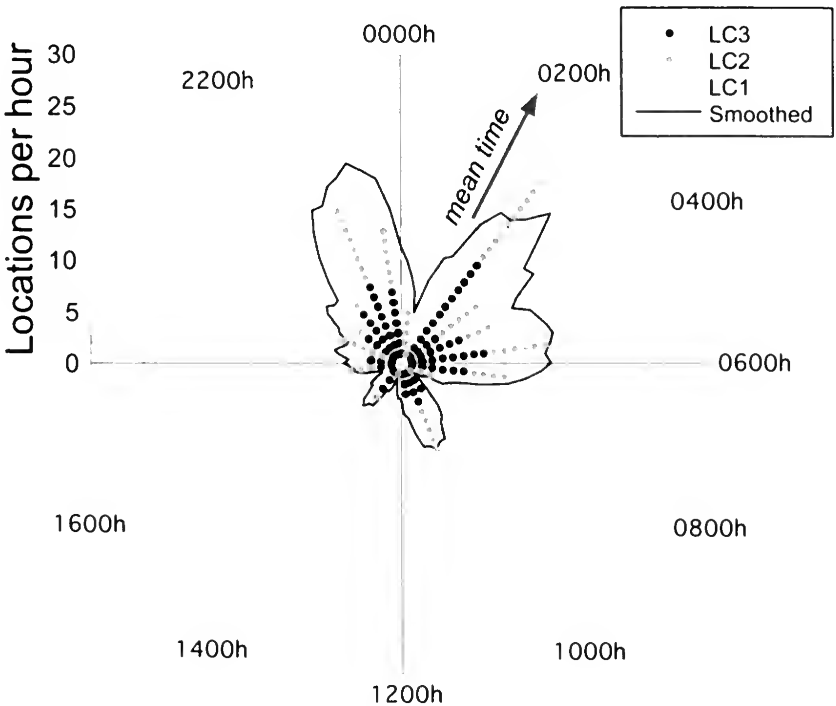

Figure 3. Circular plot showing the number of LC 3, 2 and 1 locations received at various times of the day. Locations were received on 34 days from 13 July to 31 December 2005. The locations are summarized in 24 one-hour bins. For example, the 0200-0300 h bin shows there were 12 LC 3, 10 LC 2 and 5 LC 1 locations. The smoothed line shows the moving average over a two-hour sliding window. The mean time of all locations was 0147 h (± 5.4 h, circular standard deviation). Accuracy of locations is LC 3 (± 150 m), LC 2 (± 350 m), and LC 1 (± 1 km).

No unusual weather events occurred during the study period with monthly rainfall from July to December 2005 ranging from 0.4 mm to 156 mm, a mean temperature of 27 ± 3.5 °C, humidity of 58 ± 21 % and air pressure of 1009 ± 3.4 hPa. Using fitted line regression analysis, no relationships were identified between the movement patterns of the crocodile and the four meteorological variables analysed. However, it may be that the crocodile displayed a time lag in response to environmental conditions of, for example, up to 15 days after a big rainfall. To test this hypothesis, we analysed the data further and, whilst it may be possible that more movement was identified 10-15 days after each significant rainfall, this was not certain.

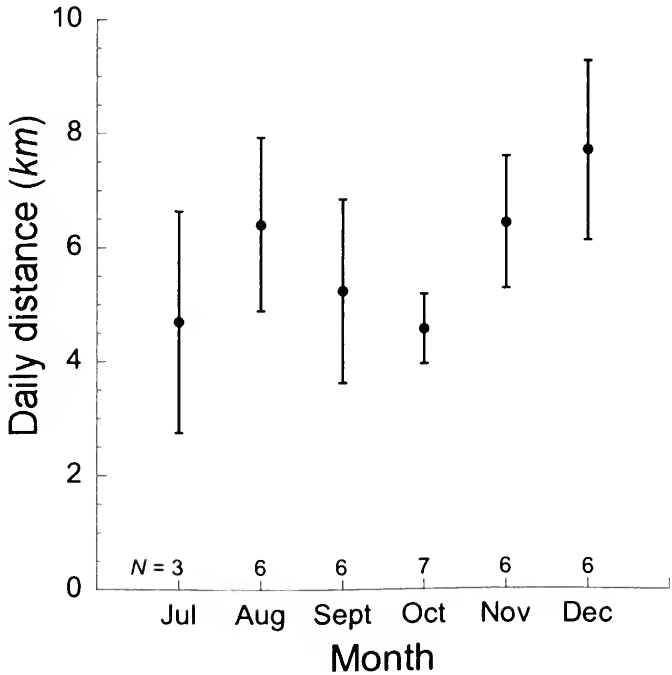

Figure 4. Plot showing the daily distances (mean ± s.e.) moved by the tagged crocodile during each month of the study.

The furthest point from the river was an LC 1 location 4.8 km directly west from the river edge on 25 November 2005 at 0116 h. The following location was an LC 2 located at 0254 h that same day right on the river edge, 5.3 km slightly south-east of the previous point, indicating a speed of 3.25 km h^{-1}. The remote weather station data show that about 75 mm of rain fell during the two weeks prior, but only 0.2 mm fell during the immediately preceding 24 hours; relative humidity at the nearest available time was 73%, whilst the temperature as indicated by the tranmitter was 29.4°C. The next furthest point from the river was an LC 2 on 2 August 2005 at 2213 h, located 4.3 km directly east of the river. As this point was the last for that 24 hour period, no consecutive following point was available for calculation of speed. The meteorological data indicated very little rainfall prior to this with only 1 mm during the month of July, with a corresponding relative humidity of 21% and temperature of 32.4°C.

Discussion

Technical effectiveness

Reviewing the reliability and functionality of tracking units can provide important information to help with interpretation of data used for ecological analysis.

The tracking unit performed well with 65% of locations obtained from the PTT being usable. This was higher than the performance obtained by Read *et al.* (2007), whose percentage of similar useable locations ranged from 32-53%. The crocodiles in the Read study had the same transmitter and duty cycle as in this study, but with slightly varying periods of attachment. The slightly higher percentage of quality readings in this study may be attributed to the crocodile moving smaller distances, thereby allowing the transmitter to acquire improved satellite fixes, and hence accuracy of location.

Many more locations were received between 2000 to 0700 h than at other times of the day (Figure 3). Satellite passes over the Darwin area were relatively evenly spaced throughout the day (J. Trede, Argos-Satellite IT Pty Ltd, pers. comm.). Brien *et al.* (2008) report the crocodiles in their study to have been most active from late afternoon (1500-1800 h) until midnight. Thus, the difference in the number of day and night locations is probably a product of crocodile behaviour and its effect on transmissions. It is likely that the crocodile was submerged in the river or within mangroves during the day, and moved on the surface in more open water, or was on open ground, at night. Although the aerial antenna on the transmitter is 185 mm in length, submerging may have covered the transmitter, making transmission difficult during the day, as it cannot transmit through water or when obscured by thick bush (Kenward 2001). To overcome these constraints, other methods including acoustic and archival tracking could also be used, potentially providing useful behavioural and physiological data for species living in aquatic environments (Franklin *et al.* 2009).

Generally, the effectiveness of Argos technology can be related to three attributes: functioning of the transmitter, performance of the Argos system and behaviour of the species being tracked. Notwithstanding the obvious advantages apparent with a system that allows remote data collection, identifying where the fault lies can often be difficult when problems do occur, due to the large distances between the researcher, the animal and the satellite system.

Until transmissions ceased halfway through the project there were no PTT or satellite receiver problems. This reduced transmission time may have been due to animal mortality, depletion of batteries, premature detachment, antenna damage or failure of the salt-water switch (Hays *et al.* 2007). When transmission ceased, an attempt was made to search for the transmitter using the VHF aerial, but this was not successful.

Because the subject of this project inhabited a smaller home range than was expected, it may have been more appropriate to have used a tracking technology with increased accuracy levels such as a Global Positioning System tracking unit with an accuracy level of < 5 m (Hulbert and French 2001). Use of this kind of unit would have permitted an understanding of variables such as time spent in the river, time spent on the riverbanks and time spent outside the river system, all of which could have provided valuable behavioural information. A more accurate unit would also have provided locations at pre-set time intervals, useful for analysing variables such as

distance or speed. The lower accuracy of the Argos tracking system (Yasuda & Arai 2005) makes analysing these kinds of variables problematic.

In addition to the direct benefits wildlife managers enjoy from satellite-based tracking systems, there are also indirect benefits such as increased public awareness and educational initiatives. This study was the first of its kind in the Northern Territory and enjoyed local, national and international media coverage. The results of the study were updated on a dedicated website every five days to enable scientists, park managers and members of the public to follow the project's progress. There was strong support for the project from both Australian and international viewers.

Ecological outcomes

Previous studies describe the abundance and distribution of crocodiles in the Northern Territory and Queensland where it has been suggested that rainfall may be an important factor influencing crocodile movement (Webb & Messell 1978). Kay (2004a) noted that male and female crocodiles in the Ord River, Western Australia, exhibited different movement patterns. He suggested that males have substantial range overlaps and that territoriality is not an important behavioural characteristic. Brien *et al.* (2008) found that males occupied larger home ranges than females during the late dry/mid wet seasons, but that this difference was not apparent during the dry season. They also concur with Kay (2004a) in that crocodiles in their study exhibited considerable home range overlap. Read *et al.* (2007) captured and relocated three male Estuarine Crocodiles in northern Queensland and used Argos tracking to study their behaviour, in particular their homing instinct. Their study confirmed that all three crocodiles behaved similarly upon release by making small and random movements around their release sites for periods of 10 to 108 days, before taking the most direct coastal route home. All three travelled up to 10-30 km a day along the coast and demonstrated definite homing instincts. A tag and recapture study of juvenile crocodiles in rivers in Arnhem Land, Northern Australia, revealed that 57-93% of crocodiles aged from hatchling to 4 years old returned to within 10 km of the original capture site (Webb & Messel 1978). Walsh and Whitehead (1993) confirmed homing behaviour during a study on the relocation of 'problem' crocodiles in Arnhem Land.

In this study, the crocodile was relatively sedentary with high site fidelity and a defined home range. Read *et al.* (2007) reported similar site fidelity for their three crocodiles once they returned to their capture locations. It is believed that the distribution of crocodiles upstream is similar to that of Barramundi (*Lates calcarifer*) in the area (Letnic & Connors 2006). The high site fidelity shown in this study would most likely indicate that the crocodile had sufficient food within the area of his home range.

According to Kay (2004a), the midstream linear range for male crocodiles ranged from 11-87 km compared to 24 km in this study. The higher rate of movement in December (the beginning of the wet season) recorded during this study conforms with that reported by Brien *et al.* (2008). They reported midstream linear ranges of

10.64 ± 2.86 ha in the late dry/mid wet season (July to January) compared with 3.20 ± 1.02 ha in the dry (May to August). Kay (2004a) showed a higher mean rate of movement during the summer wet season (December to March), of 4.0 km day^{-1}, followed by late dry movements (September to November) of 1.6 km day^{-1}, dry movements (June to August) of 1.3 km day^{-1} and post wet movements (April to May) of 1.1 km day^{-1}. Flooding of the plains adjacent to the river banks during periods of increased rain are believed responsible for this increase in movement (Webb & Messel 1978).

Whilst increased movement was recorded during the month of December in this study, the correlation between movement and meteorological variables was not significant. This may be attributed to either the low sample size (Lindberg & Walker 2007), the short observation period of this study or to the problems inherent in aligning the set daily schedule of meteorological readings with variable location times.

This study is the first in the Northern Territory to report on the continuous movement of a crocodile within an area near Darwin. Whilst the sample size precludes any statistical inference being drawn at a population level, our study was intended as a pilot to provide preliminary information about the home range and behaviour of a large male *C. porosus* in a tidal area. This has enabled us to refine our understanding of the attachment and use of Argos satellite transmitter and tracking technology as it relates to *C. porosus.*

Acknowledgements

This research was a collaboration between Massey University in New Zealand, the Parks and Wildlife Service Northern Territory (PWSNT) and the Queensland Parks and Wildlife Service (QPWS). The invaluable contributions of Mike Letnic, Tom Nichols (PWSNT), Garry Lindner (Kakadu National Park) and Mark Read (QPWS) are gratefully acknowledged. We are also grateful for technical guidance from Kevin Lay (Sirtrack Wildlife Tracking Solutions) and Mathew Irwin (Massey University, GIS lab) and for financial support from the Institute of Natural Resources, Massey University. Ethics approval to capture, sedate and attach the transmitter to a single crocodile was obtained from the Animal Ethics Committee at Charles Darwin University, Northern Territory, Australia.

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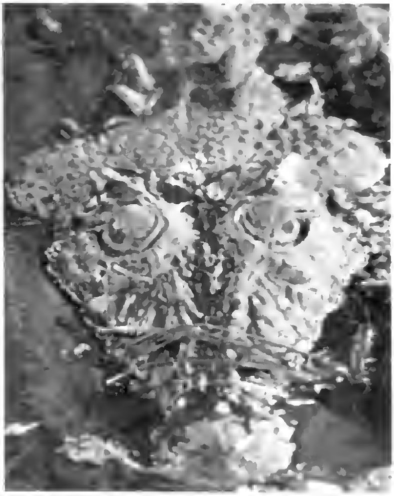
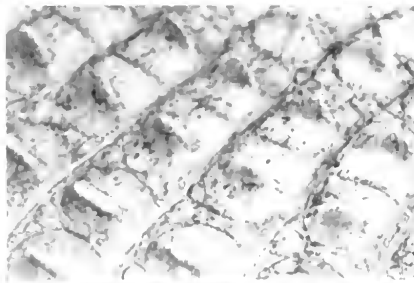
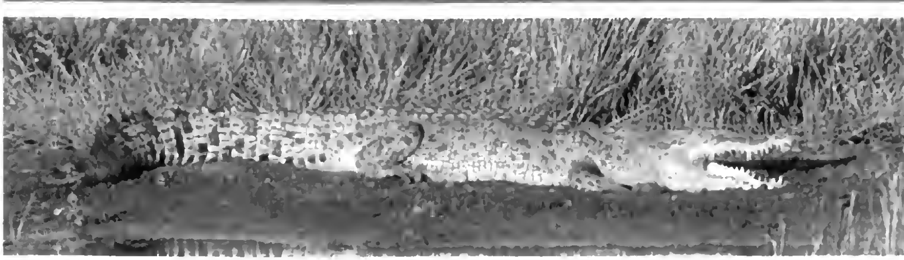




Saltwater Crocodile *Crocodylus porosus* (top left, Jon Clark; top and centre right, Ruchira Somaweera; below and bottom, Tissa Ratnayeke).



Northern Territory Naturalist (2010) 22: 75-78

An extralimital record of Grey-headed Honeyeater *Lichenostomus keartlandi* from Darwin, Northern Territory

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The Grey-headed Honeyeater *Lichenostomus keartlandi* is considered a bird of inland vegetation communities of arid and semi-arid Australia (Higgins *et al.* 2001). It is a resident or locally nomadic honeyeater endemic to northern inland Australia. Within the Northern Territory, its normal range is south of near Top Springs (16°32'37"S, 131°47'52"E) in the west and Mount Roper (14°48'59"S, 135°03'02"E) in the east (Storr 1977; Higgins *et al.* 2001). The species occurs in a variety of habitats, but primarily in low open eucalypt (including mallee) and mulga woodlands in sandstone ranges, rocky gorges, tablelands and plains; its habitat is dominated by low, stunted vegetation, often with spinifex ground cover (Higgins *et al.* 2001). It also occurs in inland riparian vegetation and less commonly in Mitchell grass dominated grasslands (Higgins *et al.* 2001).

Between approximately 1100 and 1130 hours on 21 February 2010, an adult Grey-headed Honeyeater was observed and photographed at East Point, Darwin, Northern Territory (12°24'23"S, 130°49'00"E) (Figure 1). This is *c.* 270 km (2°25') north of its previously documented range in northern Australia. The location of the sighting was in a human-modified coastal parkland/reserve, with a small patch of coastal monsoon forest (dominated by Beach Hibiscus *Hibiscus tiliaceus*) on the seaward side and a small area of adjacent tall eucalypts (dominated by Ghost Gum *Corymbia bella*) on the landward side, bounded to the south-east by a fence separating it from a horse paddock. The monsoon forest and eucalypt parkland were divided by a pedestrian and bicycle path (Figure 2).

This individual was identified as an adult by its generally bright and neat plumage, well-defined bright yellow plume extending behind and below the black posterior ear-coverts, well-contrasting dark (blackish) mask, grey head and completely black bill (Higgins *et al.* 2001). The bird was very active and was observed foraging primarily in Beach Hibiscus, where it searched leaves (presumably for insects), although it was also observed in Ghost Gums. During the observation period the bird aggressively chased, and was chased by, several Brown Honeyeaters *Lichmera indistincta* and a pair of Northern Fantails *Rhipidura rufiventris.*

Figure 1. Grey-headed Honeyeater *Lichenostomus keartlandi*, East Point, Darwin, 21 February 2010. Both photos are in Beach Hibiscus *Hibiscus tiliaceus*, the bottom alongside a Northern Fantail *Rhipidura rufiventris*. (Micha V. Jackson)

Figure 2. Location of Grey-headed Honeyeater *Lichenostomus keartlandi* sighting at East Point, Darwin, 21 February 2010. The bird frequented Ghost Gum *Corymbia bella* (foreground) and Beach Hibiscus *Hibiscus tiliaceus* (background left). (Micha V. Jackson)

A report of a Grey-headed Honeyeater from the same location was made on a local bird-watching website on 15 October 2009, about four months before the current observation. The earlier sighting was of a bird in the company of Banded Honeyeaters *Cissomela pectoralis*, of which there had been an influx into the Darwin region at that time (pers. obs.). Eucalypts were flowering at the East Point site in October 2009, attracting large numbers of honeyeaters (pers. obs.). The Grey-headed Honeyeater frequently feeds on the floral nectar of many flowering trees and shrubs (Ford & Paton 1976; Higgins *et al.* 2001) as well as foraging on insects. While both sightings possibly refer to the same individual, no observations were reported during the intervening period.

The Grey-headed Honeyeater is described as primarily sedentary, although it is also known to be locally nomadic (Higgins *et al.* 2001). Nomadic visitations, probably related to flowering events, have been noted in north-west Queensland (Liddy 1962), but overall, local and larger-scale movement patterns are poorly known. There is no documentation of extralimital occurrence in the species, but the Darwin records may be linked to movements related to resource availability. While these sightings provide

a new habitat association for the species (coastal monsoon forest dominated by Beach Hibiscus), the bird may have been attracted to the area by previous flowering of local eucalypts. The seasonal influx of Banded Honeyeaters into the Darwin region in the mid-late dry season of 2009 corresponded to local flowering (pers. obs.). The dominant eucalypt species at East Point, the Ghost Gum, flowers mainly from September to December (Brock 2001), and flowering *Corymbia* spp. (amongst a wide variety of flowering trees) are a noted food source of Grey-headed Honeyeaters (Higgins *et al.* 2001).

The normal range of the Grey-headed Honeyeater overlaps with that of the Banded Honeyeater in the southern part of the latter species' distribution (Higgins *et al.* 2001). It is possible that the Grey-headed Honeyeater at East Point had dispersed with Banded Honeyeaters, which undergo irregular coastward movements during the dry season in the Top End (the area roughly north of 15°S) of the Northern Territory (McCrie & Watson 2009). While the October 2009 sighting coincided with local flowering events, the second sighting did not, suggesting that if this was in fact the same individual, there were sufficient resources for it to remain in the area after flowering had ceased. The individual could not be relocated during weekly searches for the remainder of February and March 2010.

Acknowledgements

We thank Erica Garcia and Jon Clark, our bird-watching companions for the day the sighting was made, Aaron Petty for plant identification, Niven McCrie for information on the October 2009 sighting, and Niven McCrie and Richard Noske for comments on the manuscript.

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Persistence of gaps in Annual Sorghum following burning of fallen trees

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A previous report in the *Northern Territory Naturalist* (Andersen *et al.* 2008) described a noteworthy interaction between fallen trees, fire and Annual Sorghum (*Sarga* sp.) following a freak tornado in March 2007 that deforested approximately 3 km^2 of savanna woodland in Kakadu National Park. During the following wet season there were numerous gaps in Annual Sorghum cover associated with the burning of fallen trees during the 2007 dry season. Some of these gaps were linear and associated with burnt tree trunks, whereas others were far more extensive and associated with the burning of canopy branches. The sorghum gaps were attributed to local mortality of the seed bank due to lethal subsurface soil temperatures caused by long fire residence times, possibly associated with smouldering combustion. Many of the sorghum gaps were almost completely bare, indicating that other herbaceous species were similarly affected by high fire residence times.

At the time, it was unclear how persistent these sorghum gaps might be, nor what their long-term implications for vegetation dynamics would be. It was noted that there would be a persistent legacy if the absence of Annual Sorghum allowed the establishment or expansion of other species that then limited sorghum recolonisation.

A return visit to the site in May 2010, three years after the tornado and subsequent burning of fallen trees, revealed the sorghum gaps to be remarkably persistent. There was no evidence of sorghum recolonisation of either linear (Figure 1A) or more extensive gaps (Figures 1B, C). In most cases the gaps were still almost totally bare, without recolonisation by any grass-layer species (Figures 1A, B). There can be little doubt that seeds of a variety of species would have dispersed into the gaps over this time. Persistence of bare areas indicates that burning of fallen trees created physical or chemical conditions that are not suitable for germination or seedling growth and survival in the longer term. One sorghum gap was noteworthy in that it contained an unusually high density of acacia seedlings (Figure 1C). This will very possibly lead to the establishment of a localised acacia thicket.

These observations indicate that the burning of fallen trees might have significant long-term implications for small-scale patch dynamics. It is still unclear what these implications might be for the majority of sorghum gaps, where there is no evidence of any recolonisation more than two years after their establishment. However, the unusually high density of acacia seedlings in one gap points to the potential for major

vegetation transformation within these patches. It is also unclear if such gap dynamics routinely occur following tree fall in Top End savannas, or are peculiar to the circumstances occurring at the tornado site.

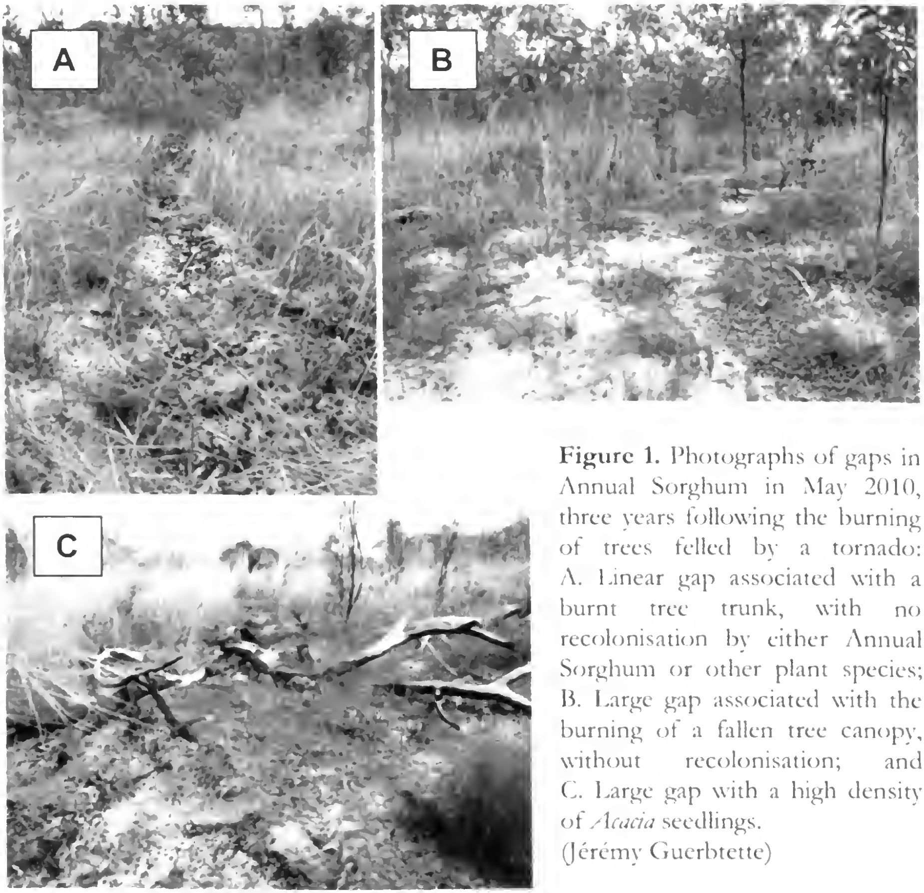

Figure 1. Photographs of gaps in Annual Sorghum in May 2010, three years following the burning of trees felled by a tornado: A. Linear gap associated with a burnt tree trunk, with no recolonisation by either Annual Sorghum or other plant species; B. Large gap associated with the burning of a fallen tree canopy, without recolonisation; and C. Large gap with a high density of *Acacia* seedlings. (Jérémy Guerbtette)

Acknowledgements

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Northern Territory Naturalist (2010) 22: 81-87

Breaking free: Gould's Bronze-Cuckoo nestlings can forge a second exit to fledge from domed host nests

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Abstract

Gould's Bronze-Cuckoos *Chalcites minutillus russatus* frequently parasitize the domed nests of Large-billed Gerygones *Gerygone magnirostris*. Here we report three instances of cuckoo chicks creating a characteristic second exit in the narrow hooded entrance of the nest upon fledging. This behaviour may help cuckoo chicks to fledge securely from domed nests.

Introduction

Dome nesting species are not common hosts for brood-parasitic cuckoos (Payne 2005) but are the primary hosts of Australian bronze-cuckoos *Chalcites* spp. (Higgins 1999). Both sub-species of Little Bronze-Cuckoo, *Chalcites m. minutillus* (Little Bronze-Cuckoo) and *C. m. russatus* (Gould's Bronze-Cuckoo) of northern Australia (Sorenson & Payne 2005; Joseph *et al.* in press), use Large-billed Gerygones *Gerygone magnirostiris*, as one of their main hosts (Higgins & Peter 2002). This host's suspended dome nest is well lined and has a hooded entrance, resulting in little sunlight reaching the nest cup. In an apparent adaptation to these unusual light conditions of gerygone nests, Little Bronze-Cuckoos have evolved cryptic eggs (Langmore *et al.* 2009). Unlike most other parasitic cuckoo species, the eggs of Little Bronze-Cuckoos do not mimic those of their host in appearance (Payne 2005). In contrast to the red-speckled, white shell typical of Large-billed Gerygones, Little Bronze-Cuckoo eggs are brown, olive or light green (Higgins 1999).

The specialization of Little Bronze-Cuckoos on dome-nesting host-species may not only affect the egg stage of parasitism but could also lead to adaptations in the cuckoo chicks. For instance, Little Bronze-Cuckoo nestlings have been found to suffer eviction from the nest by their foster parents (Sato *et al.* 2010). If the cuckoo chick evades eviction and manages to remove the host eggs and possibly nestlings through the small entrance hole of the nest, the cuckoo chick will grow up alone in an enclosed nest. This nest may not even fit the full grown cuckoo nestling (Seaton

1962), and the original hooded and usually tunnelled nest entrance could be too small to serve as an exit for a bird of that size.

We surveyed parasitized and un-parasitized nests of Large-billed Gerygones to determine how Little Bronze-Cuckoo chicks have adapted to fledging from a dome nest with a small entrance.

Methods

The study was conducted in and around the city of Cairns (16°55'S, 145°45'W) and Mareeba on the Atherton Tablelands (16°59'S, 145°25'W), within the breeding range of both subspecies of Little Bronze-Cuckoos, from October to December 2007 before the breeding season was completed. We searched for Large-billed Gerygone nests along freshwater and saltwater creek lines and in mangroves, and followed active nests with and without cuckoo chicks until fledging or nest failure. Once nests were found they were visited every three to four days until chicks hatched and then every other day until fledging. In total, 24 nesting attempts were followed to completion. Predation was determined as the cause of nest failure where the nest was punctured, ripped apart or emptied prematurely. We considered a nesting attempt as successful if the nest was empty and a family group was seen or heard in the nest vicinity. After fledging we recorded and measured any additional exit holes from the nests, but we could not obtain reliable measurements of the original entrance because the nest entrance was widened when eggs and chicks were removed for measurements as part of another study (Langmore *et al.* 2009). For one nest we documented the fledging process of the cuckoo chick with a digital camera (SONY cyber-shot, DSC-W17, 14x digital zoom, 7.2 megapixel).

Results

Our study followed 24 Large-billed Gerygone nesting attempts to completion; nine of which successfully fledged chicks, however, only two of the gerygone broods were successful as opposed to seven with cuckoo chicks (Table 1). Neither of the nests with only gerygone chicks showed a second exit, while three of seven cuckoos created a separate exit to leave the nest. Seven nests failed due to predation and three of those involved the puncture of the nest either at the side or the back of the nest (Table 1). All cuckoo chicks in our study were the sub-species Gould's Bronze-Cuckoo (*Chalcites minutillus russatus*) (unpublished mtDNA data, Langmore & Adcock).

Alternative exits created by the fledging cuckoos were invariably placed above the original nest entrance and measured (height by width in mm) 34.1 x 23.7, 28.0 x 27.6 and 29.0 x 33.0. By contrast, the alternative access to the nest during predation occurred once on the side and twice opposite the original nest entrance. A schematic drawing of one nest with cuckoo fledgling exit hole is shown in Figure 1.

Table 1. The fate of Large-billed Gerygone *Gerygone magnirostris* nests in a study population parasitised by Gould's Bronze-Cuckoo *Chalcites minutillus russatus* near Cairns, Qld.

Nest fate	Number of nests
Cuckoo fledged through original entrance	4
Cuckoo fledged through alternative exit	3
Gerygones fledged through original entrance	2
Gerygones fledged through alternative exit	0
Predation through entrance or complete destruction	4
Predation through alternative opening	3
Parasitized nests lost to unknown causes	5
Unparasitized nest lost to unknown causes	3
Total nests	**24**

We observed and photographed the fledging process of one cuckoo chick (Figure 2) that created an alternative exit in a nest suspended from a mangrove sapling at the shores of the salt water lake in the Cairns Botanic Gardens (16°54'09"S, 145°45'06"W). The process started at 0735 hours and lasted for approximately 15 minutes. During this time the host parents remained near the nest calling intermittently or visiting the nest entrance with food presumably to coax the nestling out of the nest. For the last five minutes the nestling created and repeatedly looked out of the alternative exit. After fledging, the cuckoo flew 2 m into the mangrove saplings behind the nest where it was attacked immediately by a pair of Brown-backed Honeyeaters *Ramsayornis modestus* whose nest with pin-feathered chicks was 5 m away from the gerygone nest. Both gerygone parents defended the cuckoo chick from the honeyeaters. After the honeyeaters stopped attacking the cuckoo chick, both gerygone parents repeatedly visited the nest to inspect its contents and then shepherded the chick away from the nest.

Discussion

Our report of Gould's Bronze-Cuckoo nestlings creating a specific exit in the host nest for fledging is the first description, to our knowledge, of a behavioural adaptation specific to cuckoo chicks being raised in a domed nest. This observation illustrates that the relationship between the cuckoo and its host is not only shaped by the arms race between the two species (Davies 2000) but that brood parasitism also forces cuckoos to adapt their reproductive behaviour to each host's specific ecology.

We found that holes in the nest dome created by the cuckoo were distinctive in their position. Cuckoo exits differed from holes forged by predators, possibly Black Butcherbirds *Cracticus quoyi* which hunt for nestlings in mangroves (Higgins *et al.*

2006), in that they were invariably placed above the entrance and not at the back or to the side of the nest. Another distinctive feature of holes created by predators was their untidiness with nest-lining frequently protruding from the hole. Although it cannot be ruled out that a predator could have created a hole post-fledging it is unlikely as parent activity at the nest has been found to be a primary factor to attract predators (Martin *et al.* 2000).

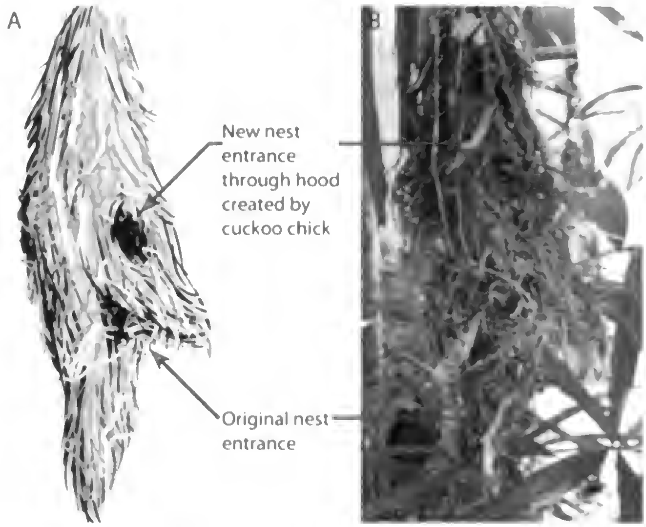

Figure 1. Line drawing (A) and photograph (B) of a Large-billed Gerygone, *Gerygone magnirostris*, nest showing both the original entrance and the exit created by the cuckoo. The nest pictured is the same as shown in Figure 2 after removal from its original location to allow safe and clear photography.

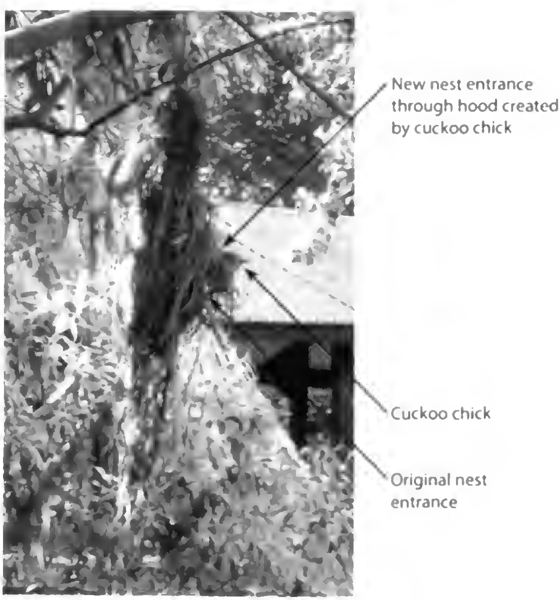

Figure 2. Chick of Gould's Bronze-Cuckoo, *Chalcites minutillus russatus*, shortly before fledging from nest of Large-billed Gerygone, *Gerygone magnirostris*, through an exit created by the cuckoo chick directly above the original nest entrance.

It is not clear why cuckoo chicks choose to create an additional exit for fledging when they are clearly aware of where the original nest entrance is, as they beg and are fed by their host parents through it. The size of the original entrance of Large-billed Gerygone nests is between 1.9-3.2 cm in diameter (Higgins & Peter 2002) and thus some entrances would be as big as those created by the cuckoo. Indeed, about half the cuckoos in our study did not create an alternative exit but used the original one. Cuckoo chicks should be able to widen original entrances that are too small as they can create wholly new additional exits, or even burst nests of dome nesting Olive-backed Sunbirds *Nectarinia jugularis* (Seaton 1962). The reason for this behaviour might therefore lie not in creating an appropriately sized exit, but in ensuring the cuckoo fledgling can leave the nest safely. The tunnelled entrances of gerygone nests could force the cuckoo to fledge downwards rather than upwards and also prevent it from surveying the area before leaving the nest. As Large-billed Gerygone nests are extremely variable in their location – in our study between 0.5 and 15 m high above water or dry land (ER, GM, unpublished data), cuckoo fledglings may drown if they left the nest downwards or were unaware of the next safe and dry place to perch. Gerygone fledglings may be less at risk of drowning, as they are further developed than cuckoos but smaller and hence possibly more agile (Andersson & Norberg 1981).

In addition, at the time of fledging cuckoo chicks are larger than adult gerygones and consequently are sitting very high in the nest dome. For such a big chick to leave a downward pointing entrance in such a low position is a biomechanical challenge. Creating a new entrance at a comfortable height and direction may thus not only be a safer but also a more 'convenient' option for the chick.

In order to conclude reasons for this behaviour further observational, and perhaps experimental, studies into Little Bronze-Cuckoo chick fledging behaviour is required. It would be worthwhile investigating any intra-seasonal or nest position and habitat variation of the occurrence of cuckoo fledging exits. Our sample in this study is too small to allow a conclusion on such variation.

The distinctive fledging exits of cuckoo nestlings could be used to indicate that a nest was parasitized. This is a particularly useful survey technique if the nests are too high to reach or can only surveyed after the breeding season. For instance, in a Northern Territory population of *C. m. minutus* along Ludmilla Creek and Leanyer Swamp near Darwin (130°51'E, 12°25'S), studied previously (Langmore *et al.* 2009), a similar opening was found in an unreachable nest after fledging and a cuckoo chick was being fed by Large-billed Gerygones nearby (GM pers. obs.). This observation is currently the only case of an additional exit in a Large-billed Gerygone nest recorded in the Darwin population. In addition five dome-shaped nests of Mangrove Gerygones *G. levigaster* were followed to fledging at this site, one of which contained a Little Bronze-Cuckoo chick. All fledged through the original nest entrance (Langmore, pers. obs).

The estimate of cuckoo parasitism achieved by this method can only be a minimum figure as not all cuckoo chicks will create an exit hole for fledging. Nonetheless, the

method can help determine the incidence of cuckoo parasitism in a gerygone population outside the breeding season from their long lived nests (Higgins & Peter 2002). Furthermore, alternative exits could prove a useful indication of cuckoo parasitism in hitherto unknown cuckoo hosts of both sub-species of Little Bronze-Cuckoo, especially in its South-east Asian breeding range where very little information on the species' reproductive biology is available (Payne 2005).

In summary, alternative exits created by Gould's Bronze-Cuckoo fledglings appear to be an adaptation to safe and convenient fledging from dome-shaped Large-billed Gerygone nests and can serve as an indication of cuckoo parasitism.

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Host and parasite:
Large-billed Gerygone (right),
and Little Bronze-Cuckoo
(below). (Trevor Collins)

Northern Territory Naturalist (2010) 22: 88-94

Exploring the adequacy of representation of butterfly species' distributions in a more accessible portion of northern Australia

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Abstract

Results of a 13-day field survey of butterflies in the Darwin – Katherine – Kakadu area in 2008 are compared with existing synoptic maps and a private national database of butterfly records. Ten records of four species are beyond distributions previously mapped for them. The most substantial extensions (> 200 km) are for a species (*Cephrenes augiades*) that may be expanding its range and another (*Nacaduba biocellata*) that may be subject to large-scale seasonal irruptions. The Darwin – Katherine – Kakadu area has been moderately surveyed by Australian standards but has only one record of each species per 3,700 km^2. Whilst it is likely that national synoptic maps of species' distributions represent the ranges of most species reasonably accurately, much remains to be learnt about butterfly distributions in the region.

Knowledge of the distribution and range size ("Extent of Occurrence" and "Area of Occupancy") of species is fundamental to defining their niche and identifying biogeographic patterns (Brown *et al.* 1996; Gaston 2003). In addition, geographic range is a key attribute used in conservation assessment (IUCN 2003; Baillie *et al.* 2004; Gaston & Fuller 2009). With reference to Australian butterflies, Sands and New (2002, p.10) stated that IUCN Criterion B – geographic range – "is the most useful criterion for butterflies" because information about other criteria such as the size, trend and dynamics of populations is available for very few taxa.

The benchmark distribution maps for Australian butterfly species are those of Braby (2000), reproduced at smaller scale and with minor modification in Braby (2004). These maps are synoptic interpretations of information collected by both amateur and professional entomologists, much of which was entered into a database by Dunn and Dunn (1991). The history, data composition (completeness, representativeness) and quality assurance processes of this database have been discussed earlier (Dunn & Dunn 2006; Dunn 2009a,b, 2010). Although holdings now exceed 132,000 records (Appendix), documentation of the distribution of Australian butterflies remains limited by the exceedingly uneven sampling in many areas of the continent (Figure 1).

The question thus arises: how well documented need the butterfly fauna be before we can have reasonable confidence that regional patterns of occurrence have been adequately described to the extent that additional surveys rarely require adjustment of synoptic maps?

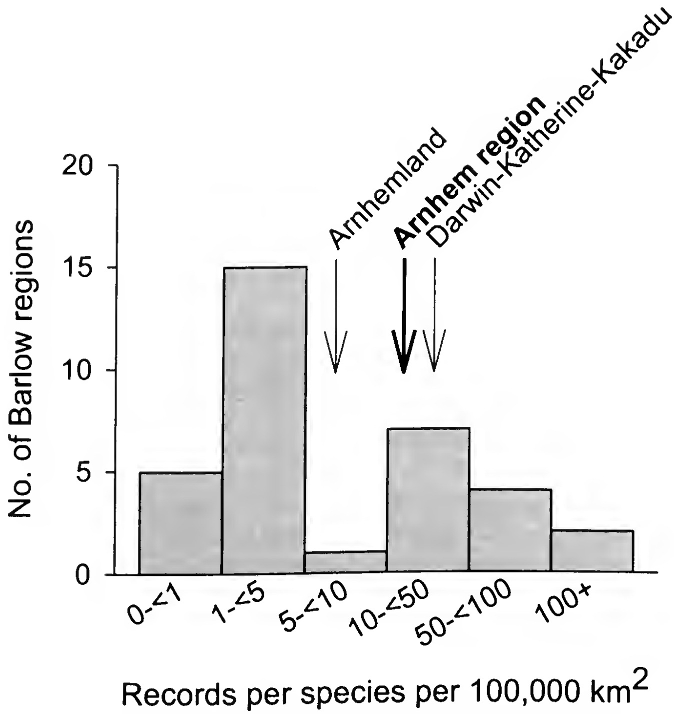

Figure 1. Intensity of records of butterfly species for the 33 Barlow regions in Australia (Barlow 1985), from the Dunn & Dunn database (1991, with updates to 2008). The relative intensity of recording in the Arnhem region (bold font and arrow) and two sub-regions within it (not bold) are shown. Data underlying the graph are presented in the on-line Appendix.

In this study, we report an evaluation of the ability of existing records and synopses to represent the range of species in the Darwin – Katherine – Kakadu area of northern Australia by comparing these with the results of a 13-day field survey conducted early in the dry season. The area is remote from the major settlements in southern Australia, but has population centres in Darwin and Katherine and, in recent decades, good road access that has made it a focus for visitors. The area is moderately surveyed by Australian standards, with an average of 27.0 records per 100,000 km^2 (which equates to one record per species per 3,700 km^2) (Figure 1 and Appendix). The

Darwin – Katherine – Kakadu area is part of the Arnhem region of northern Australia as defined by Barlow (1985) – the Top End of the Northern Territory north of 15° South. The region comprises a matrix of higher-rainfall tropical savanna (mean annual rainfall of *c.* 800-2,000 mm yr^{-1}) embedded with patches of monsoon forest, mangroves, riparian forest and other habitats (Woinarski *et al.* 2007). Typical of tropical savanna environments, the rainfall is strongly seasonal, with *c.* 90% falling in the six months from November to April inclusive (McDonald & McAlpine 1991). The main population centres are Darwin (population 110,000) and Katherine (10,000). These centres, some smaller settlements and the World Heritage-listed Kakadu National Park, all in the west of the Arnhem region, are serviced by sealed roads. In contrast, the north-eastern section of the Arnhem region comprises the Aboriginal reserve known as Arnhemland, which lacks sealed access roads and to which entry is restricted to residents and permit holders.

Butterflies were surveyed by one of us (KLD) in the Darwin – Katherine – Kakadu area over 13 days commencing 27 May 2008. Sites were selected along sealed roads from Mataranka to Darwin including Daly River, and east to Cahill's Crossing in Kakadu National Park. They were selected on an *ad hoc* basis and to be at least *c.* 2 km apart and to represent a range of vegetation types, with particular emphasis on river crossings and areas enriched with blossoming trees that may attract butterflies. Sites were surveyed between 0900 and 1730 hours. At each site, a transect of approximately 300-1,000 m or an area of *c.* 200 m^2 was surveyed for from 10 minutes to 3.3 hours (mean = 40 minutes). Butterflies were identified visually as free-flying adults or by netting, particularly those taxa that required detailed examination (e.g. Hesperiidae and Lycaenidae). In conservation reserves, where netting is prohibited without a permit, visual identification was augmented with video photography and identification of road kills. At the end of the observation period, a list of all species recorded was compiled for each site.

Each record was the occurrence of a species at a site. Records were compared with the synoptic maps of Braby (2000) and records in the private database of Dunn and Dunn as updated to 2008 (prior to the field survey) to identify locations beyond those already mapped.

During the field survey, 83 sites were surveyed, 716 records were obtained and 73 species identified in 51.2 hours of observation. Ten records (1.4%) of four species (5.5%) fell beyond previously documented ranges (Table 1), suggesting that current synoptic maps depict well the broad-scale pattern of occurrence of most species, but not all, for this region of northern Australia. Three of these four species were recorded at one extralimital location each, with range extensions of from about 40 to 220 km (Table 1). The fourth species, *Nacaduba biocellata*, was recorded at seven extralimital locations.

The range extensions documented for two species in this study, *Borbo impar* and *Elodina padusa*, are relatively minor at about 40 and 70 km, respectively. However,

Table 1. Butterfly records in the Darwin – Katherine – Kakadu area from May-June 2008 that fall outside previously documented distributions. VS = Voucher specimen retained: ANIC = Australian National Insect Collection; KLDC = KLD's collection.

Species	Date	Location	Notes
Cephrenes augiades (Orange Palm-dart)	4 June	near Cahill's Crossing, East Alligator River, Kakadu NP (12°24'S, 132°58'E)	Male photographed; shelters with larvae located. This is *c.* 225 km east of records from urban Darwin (for more details, see Dunn 2009c).
Borbo impar (Yellow Swift)	29 May	bank of Daly River, opposite Daly River Police Station (13°46'S, 130°43'E)	Male netted (VS: KLDC). A south-western extension of range of *c.* 73 km from Adelaide River (record in Angel 1951).
Elodina padusa (Narrow-winged Pearl-white)	31 May	12 km north-east of Pine Creek (13°46'S, 131°48'E)	Male netted at flowering Turkeybush *Calytrix exstipulata* (VS: KLDC). This is *c.* 40 km NNW of a record from the Cullen River (Braby 2000) and *c.* 120 km east of a record from "Daly River" (Le Souëf 1971).
Nacaduba biocellata (Two-spotted Line-blue)	30 May	Stuart Highway 46km SE of Katherine (14°39'S, 132°38'E)	Several adults present; one netted (VS: ANIC).
	30 May	Stuart Highway 42km SE of Katherine (King River Crossing; 14°32'S, 132°36'E)	Several adults present; one netted (VS: ANIC).
	31 May	15.5km SW of Cooinda turn off, Kakadu NP (13°01'S, 132°28'E)	One male, perched on Turkeybush
	1 June	40 km by road SW of Jabiru, Kakadu NP (12°53'S, 132°39'E)	One male, feeding at flowers of Turkeybush
	1 June	Nawlurlandja Lookout, Kakadu NP (12°52'S, 132°47'E)	Two adults, one photographed*; also one adult seen on 3 June
	1 June	Nourlangie Rock carpark, Kakadu NP (12°52'S, 132°49'E)	One adult feeding at flowers of *Tridax procumbens* (Asteraceae)
	2 June	Muirella Park, Kakadu NP (12°57'S, 132°45'E)	One adult feeding at flowers of Turkeybush

* This photograph was provided to the editor and referee as proof of identity.

considerable uncertainty in the precision of the historical locations, and thus in the estimation of range extensions, is applicable. Historically, collecting sites may have been described relatively inaccurately by today's standards or be subject to somewhat different interpretation because landscape nomenclature has changed over time. Of necessity, we have interpreted the locations literally, consistent with previous practice (Busby 1979). In contrast, the more substantial and more accurately known range extension for *Cephrenes augiades* suggests that this species may well be expanding its range into suitable bushland habitat. The species was possibly introduced to northern Australia relatively recently with the importation of exotic palms (its larval food plant), being first detected in urban Darwin in 1991 (DN Wilson in Braby 2000). This range expansion is consistent with several recent non-urban records in the Darwin area (Franklin 2009).

Nacaduba biocellata was previously recorded primarily from the southern two-thirds of the continent, extending northwards on the east coast to Cape York and in the Northern Territory to the Tanami Desert and southern Barkly Tableland, with outlying records in the Kimberley and at Darwin (Braby 2000). As well as in Kakadu National Park (this survey), it has since been recorded in numbers from the hinterland of the Gulf of Carpentaria in July 2006 and at four sites in Keep River National Park in July 2010 (Franklin 2007; DCF pers. obs.). Records of this species further north include a single specimen collected at Lameroo Beach (Darwin) in August 1979 (Australian National Insect Collection), and an unpublished observation from East Point (Darwin) in March 2003 (DCF). Other records of this species from many additional locations in northern Australia are held in the collections of the Northern Territory Museum and the Biodiversity Conservation (Northern Territory Government) database (M. Braby, pers. comm.). However, *N. biocellata* was not recorded in a recent extensive survey of the Darwin area (Meyer *et al.* 2006). Despite the five records from Kakadu National Park reported in this paper, extensive surveys in the Park in recent years (2003-2009) have not yielded any further records of the species (DCF, unpublished data). The status of *N. biocellata* in monsoonal northern Australia, including in particular whether appearances are seasonal and whether breeding occurs regularly, irregularly or at all, warrants further investigation. Whilst it is possible that the species breeds well north of the previously recorded distribution as presented by Braby (2000), we suggest that *N. biocellata* is at most an infrequent, irruptive visitor to the higher rainfall parts of the Top End of the Northern Territory such as Darwin and Kakadu.

Our results confirm that much remains to be learnt about the distribution of Australian butterflies. A limited field survey of an area that is relatively well surveyed by Australian standards recorded ten new locality records for four species, with two in excess of 200 km. However, these latter records were for one species that may be expanding its range, and the other for a species that may be subject to large-scale seasonal irruptions. To put our findings in context, for substantial portions of the Australian continent *any* butterfly record is likely to be more than 100 km from any

previous record. The less surveyed areas are concentrated in the vast semi-arid zone of the centre and west (Appendix). As well as being remote and relatively inaccessible, low species diversity in these regions poses a significant disincentive to butterfly enthusiasts and professional lepidopterists (Dunn 2009b). In the preparation of synoptic maps, this paucity has doubtless been partly compensated for by more extensive interpolation in areas with fewer records.

Nevertheless, our findings reinforce the fact that extrapolation from synoptic maps to the assessment of specific areas, such as for environmental impact assessment and evaluation of management issues for conservation reserves, is no substitute for further field surveys. Furthermore, the distribution of available records is likely to be geographically and taxonomically very uneven within the area. It also highlights the tantalising possibility that the geographic range of rare taxa in the area may be larger, perhaps even considerably so, than is currently understood, particularly so for cryptic species.

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We thank Ron Ninnis (Charles Darwin University) for calculating the area of the Barlow regions.

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Appendix.

Number of butterfly records per species in the Barlow regions of mainland Australia and Tasmania (data from Dunn and Dunn 1991, updated to 2008).

This appendix is available at: http://sites.google.com/site/ntfieldnaturalists/journal.

The Two-spotted Line-blue *Nacaduba biocellata* was recorded at seven locations in the Katherine and Kakadu areas. (Kelvyn Dunn)

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Notes on species of *Hyptis* Jacq. (Lamiaceae) naturalised in the Northern Territory, Australia

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Abstract

Weeds are present in all but the most pristine of environments. For anyone wishing to know when species were introduced to a region, and how quickly they have spread, the best records frequently come from herbarium specimens. Indeed, specimens provide the best means of tracking the spread of a species because their identity can be checked. Providing the species in question is readily identifiable, written records, and sometimes verbal records, can also be used with confidence. We use herbarium specimen data and written records to document the time of introduction and establishment of all three species of *Hyptis* now recorded for the Northern Territory. We also comment on some of their weedy attributes and outline early attempts to eradicate *H. suaveolens* from Darwin.

Introduction

Established weeds commonly have several attributes which help ensure their success, *viz.* annual life-cycle, rapid growth rate, self-pollination, self-fertilisation, non-specialised pollinators, asexual reproduction, numerous seed, good seed dispersal, long-lived seed bank, non-specialised habitat requirements, and secondary chemicals which protect them from pathogens and make them unpalatable to most insects and other herbivores.

As with so many members of the family Lamiaceae – which includes basil, lavender, rosemary, sage and thyme – species of *Hyptis* are aromatic and both *H. capitata* and *H. suaveolens* carry highly aromatic oils which make them unpalatable to stock. All three produce seed (technically single-seeded fruit referred to as nutlets or mericarps) which are readily dispersed; the seed often remains within the calyx segments which readily adhere to fur, wool and other fibrous material. Seed can also be dispersed by water, and in mud on shoes, animal fur and hooves, and vehicles. At least in the case of *H. suaveolens* the pericarp – the outer layer of the nutlet – becomes gelatinous when wet, and nutlets can adhere to both animals and vehicles. Vehicles driven through stands of fruiting plants will dislodge nutlets from the calyx, and on early mornings when damp from dew, swollen and sticky nutlets are commonly found adhering to vehicles (I. Cowie, pers. comm.).

An interesting aspect of the seeds of *H. capitata* and *H. suaveolens* is that they require exposure to light to germinate. Light filtering through an upper canopy of leaves is predominantly far-red radiation, a wavelength that inhibits germination, thus explaining why plants are common in exposed, disturbed areas of woodland and pasture but not in rainforest (e.g. Wulff & Medina 1971; Parsons & Cuthbertson 2001).

Two of the three species discussed here, *H. capitata* and *H. suaveolens*, are Declared Weeds in the Northern Territory (NT), both falling in schedule classes B and C under the *Weed Management Act 2001* (see Miller 2003 for a summation of the *Act*). For class B weeds, attempts should be made to control their growth and spread, while for class C weeds they should not be introduced into the NT. Only class A weeds have to be eradicated.

Key to species

1	Flowers in loose, 2 to 5-flowered groups (cymes)	*H. suaveolens*
1:	Flowers in globular clusters or dense spikes	2
2	Flowers white, in solitary globular clusters 8-10 mm diam. at flowering	*H. capitata*
2:	Flowers light blue, violet or purplish, in head-like or spike-like clusters 10-15 mm long at flowering	*H. spicigera*

Species accounts

Hyptis capitata Jacq.

A perennial herb or undershrub commonly known as Knobweed because of its globular heads of white flowers (Figure 1), this species is a native to Central America but is now a widespread weed in most of the tropical world. In Australia, it was first recorded along the South Johnstone River near Innisfail, Queensland in 1937. Parsons and Cuthbertson (2001) indicated that it was possibly introduced to this region as a contaminant of agricultural seed. It is now an established weed in coastal areas of northern and south-eastern Queensland and in the Top End of the NT (e.g. Parsons & Cuthbertson 2001; Navie 2004; Smith 2002). The species is particularly unpalatable to stock, seeds prolifically and has large reserves in the rootstock allowing it to resprout quickly and out-compete surrounding species (Parsons & Cuthbertson 2001).

Flanagan (1998) recorded that the only population in the NT was at Kakadu National Park, and that it was subject to an eradication program. Although a more precise locality was not stated, it is here assumed that the population referred to was on the margins of the park at Ben Bunga Jungle – examination of specimens at the Northern Territory Herbarium (DNA) revealed that it was first collected from that locality in May 1992 (*Russell-Smith 8809*). Plants were growing in black soil on the moist edge of the jungle. Since that time, herbarium specimens have again been collected from Ben Bunga Jungle, one gathered in 1996 (*Harwood 155*), the most recent in 2000

(*McSkimming 65706 & Mitchell*). There are no further herbarium records, but there is a report that attempts to control the species in Kakadu National Park were on-going in 2007/08 (Anonymous 2008). Patrick Shaughnessy (pers. comm.) has advised us that Knobweed is still only found in the Ben Bunga area and that only about 40 plants remain, albeit scattered over a large area.

Figure 1 (right). *Hyptis capitata* at Merauke, Irian Jaya. (Colin Wilson)

Figure 2 (below left). *Hyptis suaveolens* in flower. (Ben Stuckey)

Figure 3 (below right). *Hyptis suaveolens* in flower and fruit. (Ian Cowie)

Hyptis spicigera Lam.

An annual, aromatic herb growing to about two metres tall and with purplish, light blue or violet flowers arranged in dense spikes, this species is native to tropical America, but is now widely naturalised in various tropical countries in Africa and Asia and on many Pacific islands. Of the known non-Australian localities the nearest is possibly Timor. As with many weeds *H. spicigera* is found in an array of habitats. In Malesia, it has been recorded, sometimes in abundance, from waste places, wet rice-paddies, open grasslands and coastal coral limestone (Keng 1978). The plants are used by many people. For example, leaves can be eaten as a vegetable, seeds are eaten and used for oil production, plants may be burnt and used as a mosquito repellent and, in parts of Africa, plants and their seed are stored with Cowpeas, the insecticidal properties of *H. spicigera* protecting the Cowpeas from weevil (e.g. Anonymous, undated; Sanon *et al.* 2006).

The first herbarium record of *H. spicigera* in Australia is *D.E. Symon 7758*, a duplicate specimen of which is housed in the Northern Territory Herbarium (DNA), the original being in the State Herbarium of South Australia (AD). The specimen was collected in June 1972 and its location is recorded as 23 miles (*c.* 40 km) south-west of the Cape Caledon turn-off in Arnhem Land. No other locality or habitat notes accompany the specimen. Since then, further specimens have been collected on several occasions, all gathered within *c.* 100 km of Nhulunbuy. In September 1998 the species was recorded as being "extensive on paddock boundaries and roadside [in] open grassland area" on Garathea Cattle Property, about 70 km south-west of Nhulunbuy (*N.S. Smith 4384*). In April 2001 it was noted to be abundant in a "cattle paddock near Bulbulkbuy on Nhulunbuy to Bulman Rd ... [and] eaten by the cattle" (*A.A. Mitchell 6725*); this location is approximately the same as for the former collection. In the same month it was also collected from a slope behind the beach at the Yuduyudu Community about 17 km from Nhulunbuy (*A.A. Mitchell 6757*). It is clearly naturalised.

We are unaware of any documentation of how the species came to be established in eastern Arnhem Land.

Hyptis suaveolens (L.) Poit.

In the literature, the common name generally applied to this species is simply Hyptis (e.g. Parsons & Cuthbertson 2001; Navie 2004). The name Horehound, more usually applied to *Marrubium vulgare* L., has also been applied to this species (e.g. Miller & Schultz 2002), as has the name Schmidt's (or Schmid's) Folly.

Native to tropical America, *H. suaveolens* is now a widely dispersed weed found from Africa east to Australia, Papua New Guinea and the Pacific islands (Parsons & Cuthbertson 2001). Plants are stiffly erect, mostly annual herbs which in good conditions can be approximately three metres tall but more commonly reach about 1-1.5 m in height (Figures 2, 3). Their smallish, bluish purple flowers occur in loose

clusters in the axils of the upper leaves and, on ripening, seeds remain within the bristly calyx segments. In the Top End, seed mostly germinates after the opening rains at the end of the dry season, and plants commonly flower from about February to May. Plants usually die during the dry season, but those in well-watered areas may persist to the following year.

The easy transport of seed, by its adherence to hair and in mud, has already been mentioned and is undoubtedly an important means of spread within our rangelands. However, Parsons and Cuthbertson (2001) recorded that its spread in pastures in the Top End has primarily been as a contaminant of hay and, perhaps, pasture seed. We are unaware of any figures relating to the level of seed set in NT plants, but in what we assume to be a figure determined from a dense, healthy stand of plants in India, Raizada (2006) recorded that more than 2,000 seeds are produced per square metre. It is not an abnormally high figure for either a weed or a non-weed species (e.g. Hill 1977, table 5), but no doubt such levels have contributed to the spread of Hyptis.

The medical uses of *H. suaveolens* are widely documented, not just in its tropical American homeland but also in India and other countries where it is naturalised. Prior to British settlement of the Top End it appears that it was already in use as a treatment of respiratory and gastrointestinal infections, parasitic skin diseases, and other ailments such as colds and fever (e.g. Parrotta 2001; Moreira *et al.* 2010). The effectiveness of the antibacterial and antifungal activities of its essential oils have also attracted the attention of research workers (e.g. Mandal *et al.* 2007; Moreira *et al.* 2010).

As discussed later, the natural chemical properties of this species limited the number of potential biocontrol agents to be found in its native habitat. It is therefore no surprise that Hyptis is, and has been, used as an insect repellent in many parts of the world. In West Africa fresh or smouldering plant material of Hyptis has been used as a repellent for adult mosquitoes and, as with *H. spicigera*, leaves are used to protect stored Cowpeas from insect attack (Pålsson & Jaenson 1999; Sanon *et al.* 2006). In both the Philippines and Timor it is reported that branches are placed under beds and chairs as a deterrent to bed bugs. In the Darwin region, we know of at least one person who, to deter lice and ticks, places pieces of Hyptis leaves in the egg-laying boxes of free-range fowls.

The chemical properties of *H. suaveolens* also make it unpalatable to many Australian insects. Colin Wilson (1997) recorded only six species feeding on wild populations of Hyptis in the NT. In contrast, two other common weeds, Spinyhead Sida *Sida acuta* Burm.f and Flannel Weed *S. cordifolia* L., neither of which have obvious insecticidal properties but have a similar geographical range to Hyptis, host 20 and 23 species of plant-feeding insects respectively (Wilson & Flanagan 1990).

Unsurprisingly, *H. suaveolens* has a number of the attributes of successful weeds; its vigorous growth, readily dispersed seed and insect-repelling properties have already been mentioned. Plants are also capable of self-fertilisation and do not have a

specialist pollinator (e.g. Raizada 2006). Another attribute helping to ensure its success is the considerable variation in seed size within populations. Differences in size are correlated with variation in germination response to different light and temperature regimes and to the early size and performance of seedlings (Wulff 1973). Such variation may well enable the species to exploit different ecological niches and better compete against other species (Harper *et al.* 1970; Wulff 1973).

History of *H. suaveolens* in the Northern Territory

The earliest record of *H. suaveolens* in Australia is of a collection made by Ludwig Leichhardt. Bentham (1870, p. 80) cited a specimen "Garden Bay, Port Essington, *Leichhardt.* A common tropical American weed now found in many parts of the Old World, and probably introduced into Australia from the Indian Archipelago." From Bentham's statement and from knowledge of Leichhardt's movements (Webster 1986) it can be safely concluded that *H. suaveolens* is not native, but was growing at Port Essington at least as early as 1845, and that it was a deliberate or accidental addition to the settlement's garden. The source of the seed is less certain. It may have come from tropical America as it is known that John Armstrong, the gardener and botanical collector at Port Essington, soon after the settlement's founding in October 1838, sowed a garden with seeds and plants brought from Rio de Janeiro and Sydney (Spillett 1972). On the other hand, Bentham's suggestion that Hyptis was introduced from somewhere in Indonesia is also consistent with the recorded knowledge of the activities of Armstrong. In November 1838, camp supplies were obtained from the island of Kissa [Kisar] and these included "a variety of seeds" (Spillett 1972, p. 32). Furthermore, in February-March the following year, Armstrong selected suitable plants for cultivation during visits to Dilli [Dili], Kissa [Kisar], Moa and Coepang [Kupang]. Calley (1998) has also suggested Hyptis may have been introduced to Port Essington as a contaminant of fodder from Timor. It may also have entered via a number of other vessels, involved in trading and exploration, which had visited Port Essington before Leichhardt's arrival in December 1845.

Reporting on the establishment of *H. suaveolens*, Maurice Holtze, the first Director of the Botanic Gardens in Darwin recorded that it "was found by Leichhardt at Port Essington, and is [still] found within a limited radius of the old settlement" (Holtze 1892, p. 1). He further stated that *H. suaveolens* had also been introduced to the Top End on another occasion, this time at "Port Darwin, where it was introduced about 20 years ago by a Mr. Schmidt, from Timor, [and where] I have been able to watch its spread in the wake of settlement". He also noted that both it and *Passiflora foetida* L. were "exterminating the native vegetation wherever they have taken root, by their almost incredible luxuriance" (Holtze 1892, pp. 1-2).

Holtze was not the only person to observe the spread of *H. suaveolens.* One of us (KDLR, unpublished) has documented references to the weed in Palmerston – as Darwin was then known – in 16 editions of the *Northern Territory Times and Gazette*

from 1876 to 1880. Reports covered the introduction of the weed, and attempts to exterminate it, and included comments by the editor and the general public and minutes from meetings of the Palmerston Town Council. The first report, on 1st April 1876, confirmed the origin of the common name and reported a lack of funding – or desire? – to control the weed:

> *Mr Schmid visited Timor some years ago and brought back various seeds including a few of the beautiful and luxuriant horehound weed, now called in the Territory "Schmid's' Folly" this season it has overrun nearly the whole of the township. A deputation of the Palmerston District Council waited on the Govt Resident [GR] to ask assistance in destroying it. The GR said the government would not do it but would hire coolies to the Council at 1/- [one shilling] per head per diem for the purpose. Council is short of funds and could not accept the offer. Council could employ one white man to supervise a gang of natives who might easily be paid out of the £250 voted for their use, the expenditure of which is at present a mystery.*

In a subsequent report, dated 24 February 1877, it was recorded that council had declined an offer by the Government Resident of prison labour, at "3/6 per man per day to destroy horehound weed." A month later the following appeared:

> *The horehound weed will soon obliterate all traces of vegetation but its own in the town. On some of the unoccupied allotments it has taken thorough possession, it being impossible to pass over them through the density of the weed. In a short time if it is not eradicated, it will overrun the whole country and prove as great a curse to the NT as the (so-called) Scotch thistle and Bathurst burr have proved to the southern colonies. We were please* [sic] *to observe that Mr George Parker who has bought the Exchange Hotel Smith Street, is making an effort to destroy it in that neighbourhood. With 3 natives, two paid by the government and one employed by himself, he is clearing some allotments in his neighbourhood, many not belonging to himself....*

The desirability to attempt to eradicate the weed was again expressed on 7 April 1877 although, just two weeks later, a correspondent expressed happiness that nothing had been done to "destroy that beautiful Herbage Plant Horehound called Schmidt's folly." However, an article on the 5th of May read:

> *We are glad to see that the side of the hill adjoining the road to the Camp has been cleared of horehound weed and presents a much more pleasing appearance as well as smell. The gentlemen at present luxuriating in gaol have been engaged on the work, and we think it would be a good thing if the District Council were to follow the example set them by clearing away other places. ...*

This was followed by a note on 6 April 1878 recording that "A party of natives are clearing the horehound. It is to be hoped they will clear it beyond the Wesleyan Church to Cavenagh Street" and on 27 April 1878 "Palmerston District Council

should more closely supervise the natives removing horehound. Young plants are being left to go to seed."

More reports followed, but in essence they document the clearance of plants from the township, the Council and others now being anxious to get rid of Hyptis which was growing along the streets and clogging roadside gutters. Unfortunately, due to the aforementioned failure to remove all plants, clearance was only temporary. However, it was a concerted effort to eradicate plants, as shown in the following excerpt of 14 February 1880:

> *At the meeting of the Council on Tuesday last … Resolved that a bye law be drafted for confirmation compelling owners or occupiers of property to draw and destroy all horehound weed on their respective allotments, otherwise same to be done by Council at owner's or occupier's expense.*

Unfortunately *Hyptis suaveolens* was not exterminated and it is now found throughout much of northern NT, being widespread in the Darwin, Katherine, Gulf and Victoria River districts, and with an isolated infestation at Barrow Creek (Miller & Schultz 2002). It is also found throughout much of northern Western Australia and northern Queensland.

Hyptis was the first weed in the NT to be targeted for aerial spraying, a population on Beatrice Hill being sprayed in 1970 (Miller 2004). As well as aerial spraying, potential biological control agents have also been obtained and tested for release. A number of publications refer to this research, including Parsons and Cuthbertson (1992), C.G. Wilson (1997), A. Wilson (2001), Kissinger (2003) and Auld (2009), but the most informative is Julien (2002), in which it is noted that CSIRO Entomology began searching for potential agents in Brazil. Major surveys were conducted in 1979 and 1982, while smaller surveys in Mexico and Venezuela occurred in 1981. During this work it was noted that there is considerable morphological variation within *H. suaveolens* and that the plant's natural chemical protection limits the suite of potential agents available for testing. More were discovered during 2000-2002 following further work in Mexico and Venezuela; these included flower-feeding beetles, leaf- and stem-feeding weevils, and assorted moths.

Mic Julien (pers. comm.) has indicated that the program, originally initiated by CSIRO on behalf of the NT Government, ceased after 2002. Julien *et al.* (in press) discuss in some detail the various agents tested and the problems encountered in the search for suitable control agents for Hyptis. To date, nothing suitable has been found, but the authors indicate that some potential agents warrant further testing.

Just why Hyptis was introduced to Darwin and Port Essington does not appear to have been stated in any early documentation. It may have been deliberate because it was considered to be an attractive addition to the garden. However, medicinal and insecticidal properties of Hyptis may also explain its introduction. The use of herbs

for medicinal purposes and as insect repellents is a practice many hundreds of years old and, as previously outlined, there is a history of Hyptis being put to such use.

Finally, we note that the referee of this article drew our attention to anecdotal reports that Hyptis was drunk as a tea or tonic by early Chinese residents of Darwin, and that the Chinese may have been responsible for its introduction. Although anecdotal, these reports support the notion that the introduction of Hyptis to Darwin, and perhaps also Port Essington, was deliberate. However, any belief that the Chinese brought Hyptis to Darwin is not supported by published records. The Chinese did not settle in the NT until August 1874 (De La Rue 2004) and in the report of 1st April 1876 in the *Northern Territory Times and Gazette* it was specifically stated that Hyptis was introduced "some years ago" by Schmid.

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Hyptis *Hyptis suaveolens* is an abundant weed
in the Top End of the Northern Territory. (Deb Bisa)

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Book Review

The Top of the Top End: John Gilbert's Manuscript Notes for John Gould on Vertebrates from Port Essington and Cobourg Peninsula (Northern Territory, Australia): with Comments on Specimens Collected during the Settlement Period 1838 to 1849, and Subsequently

By Clemency Fisher and John Calaby. *The Beagle, Records of the Museums and Art Galleries of the Northern Territory*. Supplement 4. Museum and Art Gallery Northern Territory, Darwin, Australia & World Museum, Liverpool, UK. 2009; iv + 240 pp; paperback. ISSN 1833-7511. Price A$66.00.

This latest supplement of *The Beagle* is a marvellous publication for anyone interested in the history of the discovery of Australia's flora and fauna. It is a meticulously researched, highly readable and beautifully illustrated work.

The book commences with a Preface by David Attenborough in which he reminisces about his time in Kakadu National Park and his meeting with the late John Calaby, an "unpretentious and modest" man and "one of the outstanding Australian taxonomists of his era and a particular expert on its mammals". Following the Abstract the 28-page Introduction tells us that the aim of the work was to draw together information about existing vertebrate specimens from Port Essington and the Cobourg Peninsula, with particular emphasis on the collections and manuscripts pertaining to John Gilbert. The other specimens referred to include those gathered by collectors during the time Port Essington was occupied from 1838 to 1849, by the CSIRO expeditions between 1965 and 1968 – the results of which were published in Frith and Calaby (1974), and by a few other individual researchers.

Much of the Introduction is dedicated to a short history of Victoria, the Port Essington settlement, and gives an outline of the various collectors of objects of natural history, with Gilbert a stand-out contributor. To quote from the book "Gilbert's Port Essington specimens alone represent about fifty new species or subspecies of birds and animals ... Gilbert also collected many other new forms on the Cobourg Peninsula, particularly fish ..., reptiles, molluscs ..., and insects ..." It isn't actually stated, but I believe the wording is meant to imply that Gilbert collected the type specimens of these taxa.

Much credit is also given to John MacGillivray (aboard *H.M.S. Fly* and *H.M.S. Rattlesnake*); others of importance include John Lort Stokes (*H.M.S. Beagle*), Benjamin Bynoe (*H.M.S. Beagle* and later *H.M.S. Fly*), Captain William Chambers and Assistant Surgeon Sibbald of the colony's ship, *Pelorus*, and Joseph Beete Jukes and John Ince (both *H.M.S. Fly*). I have a minor criticism here in that the major botanical collector from Port Essington, John Armstrong, is not mentioned among the natural history

collectors. Armstrong, the settlement's gardener, collected hundreds of specimens, about 30 of which are types. His contribution to the early knowledge of biodiversity in the Port Essington region is probably second only to that of Gilbert.

The Introduction also includes a reproduction of Gilbert's letter to John Gould dated 19th September 1840. Among other things he noted how the heat and humidity "brings on such a degree of lasitude [sic] and weakness, that I have now adopted the plan of going out by the dawn of day, and the cool of the evening" to collect. The renowned scientist Thomas Huxley, aboard *H.M.S. Rattlesnake*, expressed similar views of the climate to those of Gilbert, noting that "Port Essington is *worse than a ship*, and it is no small comfort to know that this is possible." (Huxley 1935).

The introductory chapter concludes with a list of acronyms for museums and libraries holding specimens and manuscripts relating to natural history collecting at Port Essington; there are 30 such acronyms, a figure reflecting just how big a task it was to bring this monograph to fruition. Indeed, it is noted on p. 211 that it "is the result of intensive ferreting done over the last 25 years in order to locate and analyse [Gilbert's] specimens". It was common for specimens from the antipodes – and elsewhere – to have been widely dispersed to interested parties in Europe, both before and subsequent to their formal naming. In part, Gilbert's specimens may be more scattered than most due to the entrepreneurial nature of Gould, but the sale of Gould's primary collection of Australian birds on which the descriptions of many of his new species were based very much added to the difficulty. Gould had offered his primary collection to the British Museum for the sum of £1,000 but it was turned down and, with Gould apparently outraged and determined to humiliate the trustees (Tree 1991), the collection subsequently came to rest in what is now the Academy of Natural Sciences, Philadelphia (ANSP). The collection was sent to the USA via Paris where taxidermists mounted all the specimens but, in so doing, stripped many of them of their original labels. This, unsurprisingly, "caused endless problems with identifying Gould's bird types, or establishing the data for other important individuals."

The bulk of the monograph lists vertebrate species collected from Port Essington. It is arranged in four parts. Part 1 deals with nearly 40 species of fish, of which five are illustrated, including colour photographs of four holotype specimens collected by Gilbert. Part 2 opens with a transcript of a two-page manuscript account by Gilbert entitled "Reptiles of Port Essington", that consists solely of an account of the Frilled Lizard. Thirteen frogs, one crocodile, six turtles, 26 lizards and 32 snakes are listed in this section. Part 3 covers 28 species of mammals and opens with a transcript of Gilbert's manuscript "Quadrupeds of Port Essington", while a copy of the hand-written manuscript is provided in Appendix 1. Part 4 deals with birds, more than 200 of them. As with the other lists, it is one in which to dabble to find information about the Port Essington naturalists and their collections, and Gilbert's observations of birds. It ends with assorted tables, including one listing bird species recorded for the Cobourg Peninsula against the collector; another lists avian scientific names based on type specimens collected from Port Essington.

In all four parts the meticulous recording of specimen data and associated references is highly impressive. Importantly, the layout is such that it is easy for anyone to scan the text for collectors of interest. Until such time as all herbaria and museums electronically catalogue their specimens *and* make them readily available, publications such as this are important to taxonomists and historians of natural history.

The book concludes with a long list of references and several appendices, including one containing "John MacGillivray's species list from *H.M.S. Fly*, largely from Port Essington, dated May 1845", and an index of species names, scientific and common.

This work abounds with illustrations, there being 145 figures in total. Almost all are in colour and of these 60 are of museum specimens, many of which are types. Figures are frequently accompanied by notes, often including information additional and complementary to that in the main text. Included amongst the figures are ten full-page illustrations of paintings taken from Jardine & Selby's *Illustrations of Ornithology* (1830), Gould's *The Mammals of Australia* (1845-1863) and Gould's *The Birds of Australia* (1840-1848). These include plates from Gould's ornithological work depicting both black-headed and red-headed forms of the Gouldian Finch.

The science of systematics produces many publications in the form of taxonomic revisions and monographs which list the specimens examined and, as such, these publications are a valuable resource to historians and natural historians, not just professional taxonomists. Sadly, I have little doubt that these publications are rarely examined by historians because the works are seldom well-publicised, readily available or easily understood by those without a scientific background. However, this book is exceptional in that it is not only accessible but the information it contains should be understood by all who read it. I urge anyone with an interest in northern Australian natural history and the history of collectors and collections to delve into this well-produced work. Clemency Fisher, the late John Calaby and a succession of editors of *The Beagle* (Helen Larson, Dirk Megirian, Chris Glasby and Richard Willan) have produced a most valuable reference which is deserving of a wide audience.

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